JOURNAL OF

METALS

AUGUST 1960

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JOURNAL OF

METALS

Vol. 12, No. 8
August, 1960

COVER: "I must down to the seas again . . . ." and with that our artist, David Cain, took forth on this month's cover dedicated to "Metallurgy in the Navy", the theme of this issue.

personnel 586
education 588
personal 591
reporter 599
editorial 603
news of your profession 643
coming events 648
advertisers index 648

Columbium Symposium, Draws 200 590

AUGUST 1960 TRANSACTIONS CONTENTS 596

METALLURGY IN THE NAVY

1. The Navy's R&D Program 606
by Julius J. Harwood

2. The Navy's Refractory Metals Program 611
by T. F. Kearns and J. Maltz

3. Direct Energy Conversion 615
by Paul H. Egli

4 Semiconductor Research in the Navy 620
by W. W. Scanlon

5. Irradiation Effects in Magnetic Materials 622
by E. I. Salkovitz

BRINGING AIME TO THE MEMBERS 627
(Southwest, Pacific Northwest, and New England Conferences)

U. S. Steel Opens Electromechanical Building 632

Italy Investigates Direct Reduction of Iron Ore 634
by Antonio Scortecci

INFAB For Hot-Working Refractory Metals 636

ANNUAL MEETING: IMD Sessions Report 637

PHASES AND PROCESSES
Short-Time, Rapid-Heating, Elevated Temperature Testing 641
by Robert E. Mihalco

Metallurgy of Elemental and Compound Semiconductors Program 644

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personnel

● These items are listings of the Engineering Societies Personnel Service, Inc. This Service, which cooperates with the societies of Civil, Electrical, Chemical Mechanical, Mining, Metallurgical, and Petroleum Engineers, is available to all engineers, members and non-members, and is operated on a nonprofit basis. If you are interested in any of these listings, and are not registered, you may apply by letter or resume and mail to the office nearest your place of residence, with the understanding that should you secure a position as a result of these listings you will pay the regular employment fee of 60% of the first month's salary if a non-member, 50% if a member. Also, that you will agree to sign our placement fee arrangement which will be mailed to you immediately after receiving your application. In sending applications be sure to list the key and job number. The New York office of Engineering Societies Personnel Service, Inc., is open for interviews until 7:00 p.m. Thursday evenings.

● When making application for a position, include eight cents in stamps for forwarding application to the employer and for returning, when possible.

—MEN AVAILABLE—

All those listed under "Men Available" have membership in the AIME.

Metallurgist (nonferrous); two years of education, Illinois Institute of Technology, age 45. Eighteen years experience in laboratory and production. Metallographic experience in ferrous and nonferrous alloys. Vacuum casting and rolling mill methods and procedures. Prefer Midwest or foreign. M-1125-Chicago.

Foreman or Superintendent; MetE, age 28. Seven years experience in charge of crews, developing undercut blocks in block caving, safety inspection, cut and fill stopes, flotation mill, underground surveying on copper and molybdenum mining. $8500. Prefer West or foreign. Se-1648.

R&D Engineer; ME, Phys Met, age 39. Seven years research on metals and teaching assistant for university. One year application of heat treatment of metals. $7000. Prefer San Francisco East Bay. Se-1151.

Manager or Superintendent; age 53. Thirteen years as manager of mines, supervising all production, purchasing, operations, exploration and development, and negotiating labor contracts. Twenty-five years as mill superintendent, supervising maintenance, ore dressing, operations (lead, zinc, silver, copper, gold, mercury). $9600. Prefer West. Se-905.

Mine Manager; MinE, age 62. Thirty-six years experience, as general manager, superintendent of both foreign and domestic mill and mine construction, development, operations, facilities, (gold, silver, base metals). $12,000. Prefer Southwestern US, or any. Se-864.

Metallurgist, Teacher; B.S. Min, EM Met, age 57. Twenty years experience. Built mills; was superintendent and manager over metal mining and milling. Two years sales of fuel additives for chemicals manufacturer. One year associate professor of mining and metallurgy. $6000. Locate anywhere. Se-1772.

Chief Metallurgist; MetE, age 34. Ten years diversified experience in ferrous and nonferrous foundry . . . cold and hot forging . . . production . . . and research and development of titanium . . . stainless . . . superalloys . . . creep . . . and fatigue. $12,000. Prefer West. Se-1025.

—POSITIONS OPEN—

Metallurgist, Metallurgical Engineer, or Chemical Engineer, with five to six years experience in the brass industry. Should have melting room experience. Salary, $7000-$9000, depending on applicant. Location: western Pa. W9220.

Mill Foreman with considerable maintenance experience and a good knowledge of lead-zinc metallurgy and amalgamation or a new 500-tpd mill which will begin in the fall. Salary to start, $6000. Location: West. W9216.

General Mechanical Foreman with four to five years experience in metal refining plant. Salary, $10,000. Location: Md. W8974 (c).

Assistant Plant Metallurgist or Mill Foreman to supervise phosphate rock operation. Should have knowledge of crushing, grinding, cycloning, flotation, filtering, pumping and drying operation, and equipment. Interest in flotation research desirable but secondary to operations. Will have complete and independent charge of operations of present plant upon completion of new plant now under construction. Phosphate rock producer in West. $600 per month to start. Sj-5383.

Sales; MetE or equivalent and five to ten years foundry or engineering sales experience relating to metallurgy. Will provide technical sales assistance on ferrous castings. For a ferrous foundry. $700-$800 per month, depending on qualifications. Location: Los Angeles area. Sj-5357.

Plant Engineering and Production; EE, MetE, with seven to eight years working experience related to ore reduction and milling. One opening for mechanical engineer, one for electrical engineer familiar with heavy electrical usage. Another spot for metallurgical engineer to do production control. Must be familiar with equipment and work in an ore reduction and metals processing plant. Salary commensurate with experience. Location: Nev. Sj-5349.

Pilot Plant Superintendent; Met or MinE, experienced in pilot plant ore dressing operations (heavy media, jigging spirals, flotation, magnetic separation) for iron ore operation. Must have working knowledge of Spanish. Possible family housing after two to three months single status. For an open pit mine operation. Salary, about $9600, plus benefits. Location: South America. Sj-5210.

Engineers. a) Metallurgist for R&D; to devriop new uses in the rare earth field. b) Application engineer; chemist, metallurgist, or physicist with some contact with materials used in electronic vacuum tube parts. Salaries open. Location: northern N. J. W8845.

Metallurgist. Graduate with approximately three years industrial experience. To assist chief metallurgist in evaluating incoming materials, assist production, and develop new equipment in connection with magnetic materials, nickel iron, and silicon iron alloys for tape and bobbin cores. Salary, about $8500. Location, southern N. J. W8827.

Sales Trainee for metals sales division. Recent graduate in metallurgical, chemical, or mechanical engineering with desire to enter the field of industrial sales. Minor travel during training period. Headquarters: New York City. W8817 (b).

Consultant; metallurgist with wide metallurgical experience in copper smelting and refining, and familiarity with operation and engineering in copper-producing areas throughout the world. Will provide technical direction for metallurgical plant and design construction, also technical assistance to operate smelters and refineries, plus handling developmental work for new methods. Must be top-notch with sound economic sense and be capable of contact work under a variety of circumstances, including top management. Salary commensurate with experience. Headquarters: Mountain States. Sj-5265-R.

Address replies for positions to the nearest local office of the Engineering Societies Personnel Service, Inc., *not* to the JOURNAL OF METALS. Offices are located at 29 E. Madison St., Chicago 1, Ill. . . . 57 Post St., San Francisco, Calif. . . . and 8 W. 40th St., New York 18, N. Y.

Research Metallurgist; Met, with ore dressing experience. For laboratory research in large copper mine in the southwest. Apply by letter. Salary, open. Sj-5241.

Research Metallurgist, preferably with Ph.D. or equivalent. For research and development in physical metallurgy of aluminum alloys. Salary commensurate with experience, plus liberal employee benefits. Location: Pacific Northwest. Sj-5240.

A weekly bulletin of engineering positions open is available to AIME members at a subscription rate of $3.50 per quarter or $12 per annum; $4.50 per quarter or $14 per annum for nonmembers, payable in advance. Local offices of the Personnel Service are at 8 W. 40th St., New York 18; 57 Post St., San Francisco; and 29 E. Madison St., Chicago 1.

NEW BULLETIN

A new bi-weekly bulletin of "Engineers Available" is now being published by the Engineering Societies Personnel Service, Inc. Distributed free of charge, the bulletin contains synopses of the experience of engineers who have registered with the Service and are seeking a new position.

Any employer interested in receiving the bulletin should so advise E.S.P.S. at 8 W. 40th St., New York 18, N.Y., and your name will be placed on the mailing list. Any engineer who is registered with the Service or wishes to register is entitled to a 35-word notice in the bulletin. Write to the New York office for forms. Your qualifications will be brought to the attention of employers on our mailing list without revealing your identity.

It is planned to extend the publication to the midwestern and western offices in the near future.

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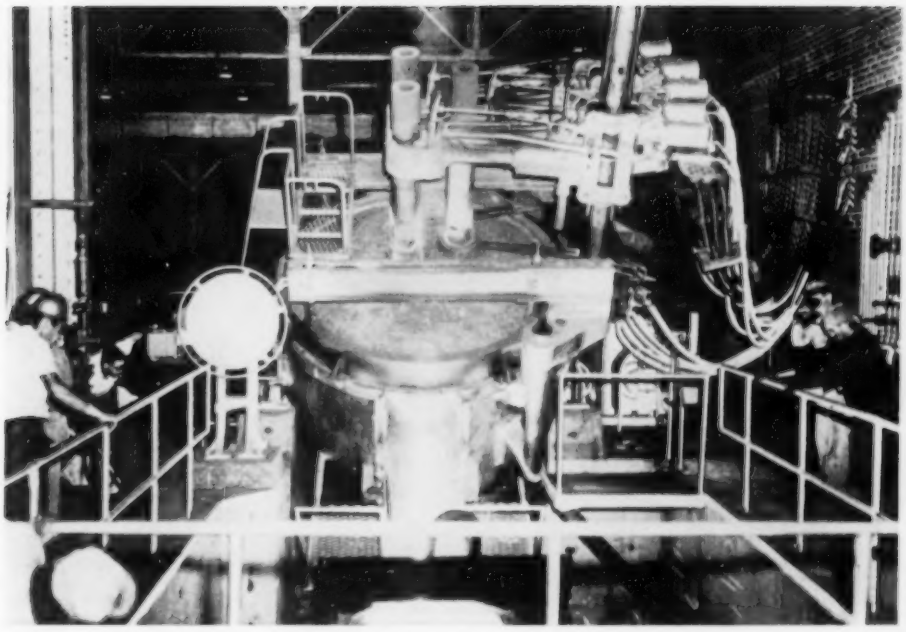

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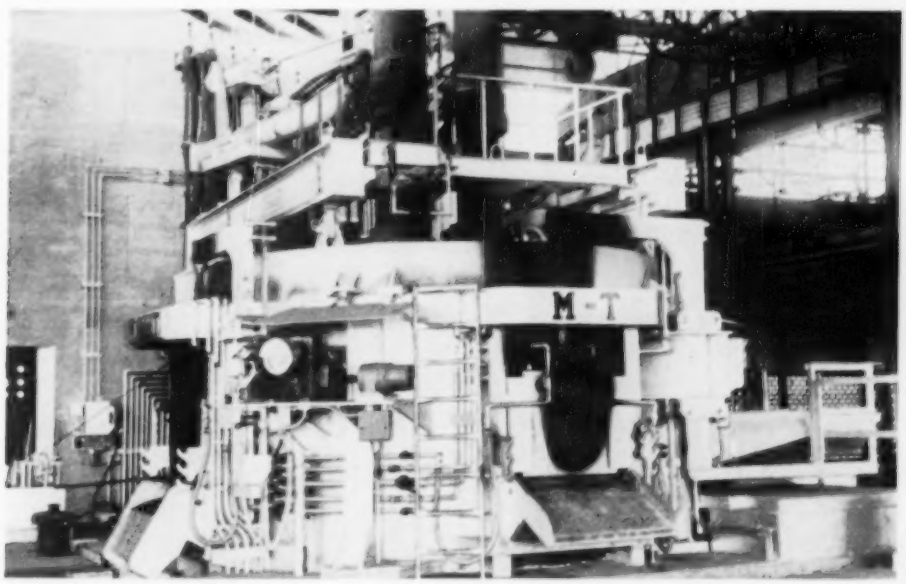

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education

NUCLEAR ENGINEERS

A study of the education of this country's nuclear engineers will be instituted in September under a grant by the Atomic Energy Commission. A Committee on Objective Criteria for Nuclear Engineering Education will undertake the year-long study. Members will come from industry, government agencies, and colleges and universities throughout the country. Heading this 30-man Committee will be Glenn Murphy—chairman of the Dept. of Theoretical and Applied Mechanics, Iowa State University. The study is being jointly sponsored by the American Society for Engineering and the American Nuclear Society.

HONORS PROGRAM

► The Polytechnic Institute of Brooklyn will initiate an honors program in science and engineering in the fall. Under the program exceptional students will be able to receive a doctorate in six years of full-time study. No strict dividing line is provided between undergraduate and graduate work. Honor students will receive a common curriculum the first two years, concentrating in mathematics, physics, and the humanities. After that they may begin their specializations, which include metallurgical engineering.

Although the program is designed to educate research scientists and engineers from the freshman year through the doctorate, students will be awarded a B.S. at the end of the undergraduate portion of their studies.

The program, made possible by a $700,000 grant from the Ford Foundation, will allow the Institute to release faculty members from normal teaching loads . . . permit visits from faculty of other institutions . . . and enable fellowships and loans to be awarded graduate students in the program.

Thirty-three of approx 500 September freshmen have been selected to begin the program.

LITERATURE

► The properties of the refractory metals tungsten, molybdenum, tantalum, and columbium are compared in a chart just published by Fansteel Metallurgical Corp. On the chart's reverse side is a conversion of degrees Fahrenheit to degrees Centrigrade and vice versa. Also included are formulae for exact conversions arithmetically.

For copies, write Fansteel Metallurgical Corp., Dept. JM-3, Metals and Fabrication div., North Chicago, Ill.

► The Alloy Casting Institute has issued a 12-pp. *Technical Publications List*. The booklet lists 46 technical papers, articles, reprints, and data sheets which have resulted from the Institute's informational program.

Write the Alloy Casting Institute, 1001 Franklin Ave., Garden City, N. Y.

► *Molybdenum Metal* is the title of a 110-pp. handbook published by Climax Molybdenum Co., div. of American Metal Climax, Inc. The handbook emphasizes new advances in arc casting and powder metallurgy. The physical and mechanical properties of unalloyed molybdenum metal are also treated. Request copies from Climax Molybdenum at 1270 Avenue of the Americas, New York 20, N. Y.

(See Materials Research p. 598)

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Columbium Symposium Draws 200

A top-notch technical program and pleasant off-season resort surroundings proved an irresistable combination for nearly 200 registrants at the recent Columbium Metallurgy Symposium sponsored by the Hudson-Mohawk Section of AIME in cooperation with The Metallurgical Society. The site of the June 9-10 conference (the first sponsored by this relatively new section) was the Hotel Sagamore, located on the western shore of Lake George at Bolton Landing, N. Y.

With most conferees arriving and registering the previous evening, it was possible for Conference Chairman, D. L. Douglass, of G. E.'s Knolls Atomic Power Laboratory, to start the first session promptly at 8:30 Monday morning. He described the conference as perhaps the first opportunity for those working in various phases of columbium metallurgy to review their collective progress and indicated that attendance at the meeting confirmed the need for such an opportunity. Mr. Douglass then introduced Professor A. A. Burr of Rensselaer Polytechnic Institute, Past-Chairman of the Hudson-Mohawk Section of AIME, who welcomed those attending the conference on behalf of the Section and its present Chairman, J. J. Gilman of the G. E. Research Laboratory, who was unable to attend.

A total of 30 papers was presented in four sessions dealing with fabrication, mechanical properties, general metallurgy, and oxidation and corrosion of columbium and its alloys. Distribution of preprints of the papers and a limit on time for their presentation permitted extensive discussion of the results reported by the speakers.

A technical summary of the conference will appear in the Phases and Processes columns of the September JOURNAL OF METALS.

The first day's activity was climaxed by the customary social hour and fellowship dinner beginning at 6:00 pm. In introducing the head table guests, Conference Chairman D. L. Douglass called upon AIME President, J. L. Gillson, who attended the entire conference. President Gillson recalled having recently observed similar groups of engineers and scientists at other AIME-sponsored sessions attacking such subjects as reservoir engineering in petroleum production and geology of mineral deposits. He emphasized the similarities in background and approach as being more important than differences in technical interests of AIME members. Such similarities, he stated, are responsible for the continued growth of the Institute through its Societies and local sections.

Mr. Douglass next called upon R. M. Parke of the G. E. Research Laboratory to introduce the speaker for the evening. In introducing W. J. Harris, Jr., Dr. Parke cited a long list of accomplishments, of which the last, but far from least, was to have gone swimming in the frigid waters of Lake George earlier that day. Dr. Harris, currently a Director of The Metallurgical Society from the Institute of Metals Division, is associated with the Materials Advisory Board of the National Science Foundation. He reviewed briefly the materials problems which had arisen and been solved in the US over the past decade, with a view to forecasting the types of problems to be faced in the immediate future. Among these problems, Dr. Harris included the following: production of structural materials for high-temperature applications . . . understanding the conditions to which coatings are subjected . . . development of superstrength materials requiring a detailed and accurate understanding of the relationship of structure to properties . . . and, finally . . . problems inherent in processing materials which may be developed to meet new requirements.

With the conference coming to an end the following day, registrants seemed to be unanimous in their agreement on two points: 1) future technical conferences at similar sites are much to be desired; and 2) it should be possible to take advantage of the surroundings without missing papers of interest. Program planners, take note!

Those responsible for the success of the Lake George meeting include: D. L. Douglass, Conference Committee Chairman; A. E. Bibb, Treasurer; F. W. Kunz, Advance Registration and Program; C. T. Sims, Program; and R. M. Goldhoff, Publication, all of General Electric Co.'s Knolls Atomic Power Laboratory, as well as J. R. Hughes, Arrangements; S. J. Noessen, Travel; and R. E. Keith, Publicity, all of the G. E. Research Laboratory. Membership activities were well handled by the Hudson-Mohawk Section's R. J. Allio, also of Knolls Atomic Power Laboratory.

DCJ

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personals

Williams Rodgers has been appointed chief metallurgist for the Republic Steel Corp. Mr. Rodgers succeeds Earle C. Smith, who died May 20th. (See Appreciation, p. 647). **Andrew G. Forrest** takes over Mr. Rodgers' former position as asst. chief metallurgist. Forrest's former title was asst. to the chief metallurgist.

William B. Wallis was recently named co-winner of the Trinks Award for achievement in industrial heating equipment. *Industrial Heating* magazine made the presentation. Mr. Wallis, consulting engineer for Strategic Materials Corp., was cited for his pioneering in development of electric arc melting furnaces. **Ernest W. Weaver**, retired executive of Surface Combustion, was the second recipient for advances that he made in heat treating furnaces.

Herman F. Ramstad has been named senior research metallurgist in Jones & Laughlin Steel Corp.'s Research div. Dr. Ramstad had been a research engineer at J & L since February 1959.

George C. Floyd is now senior vice president at Vanadium Corp. of America. He has been associated with Vanadium Corp. as a vice president since 1951.

W. J. Kroll, consulting metallurgist of Corvallis, Ore., has been appointed the sixth Castner Memorial Lecturer. He will deliver a talk on *The Fusion Electrolysis of Titanium* in Glasgow, Scotland, on Oct. 7th.

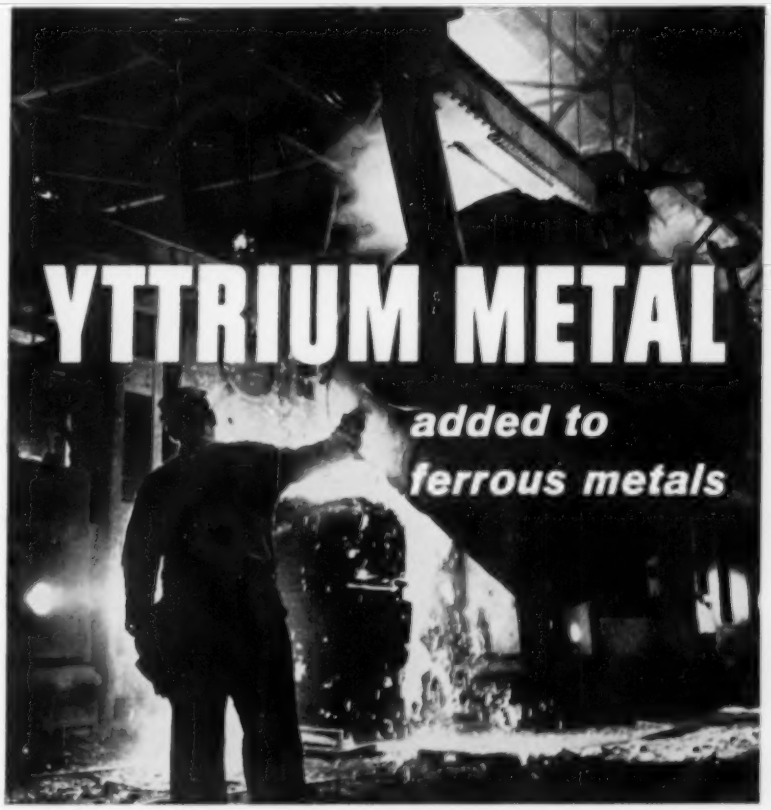
Frank W. Chambers has been elected president of Strategic Materials Corp. He joined the company as an executive vice president last fall, after having served as director of engineering for Kennecott Copper Corp. for nine years.

Robert E. Edwards and **William D. Smith** were among recent appointments in Jones & Laughlin Steel Corp.'s Aliquippa works. Mr. Edwards is now asst. superintendent—open hearth dept. Previously, he was asst. superintendent—converting. Mr. Smith moves up to asst. superintendent—converting, having formerly been general foreman—basic oxygen.

Ethan A. Smith, Jr., is now manager of beryllium metal sales for The Beryllium Corp. He was formerly manager of development engineering in the Corp.'s Nuclear div.

Edward E. Hucke, associate professor of metallurgical engineering, The University of Michigan, has been

(Continued on page 594)



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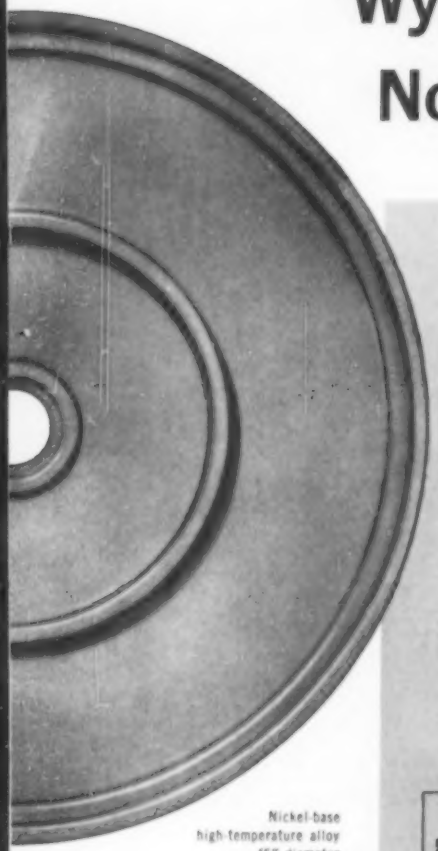

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520 pounds

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19" diameter
143 pounds

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TENSILE AND YIELD STRENGTHS	Waspaloy	RT	A	175,000	120,000	15.0	194,000	136,000	24.0
		1000	A	162,000	112,000	13.0	175,000	124,000	23.0
	René 41	RT	B	180,000	132,000	12.0	200,000	150,000	15.0
		1400	B	135,000	115,000	13.0	145,000	125,000	18.0
	Astroloy	RT	C	190,000	138,000	10.0	205,000	152,000	12.0
		1400	C	150,000	122,000	12.0	160,000	132,000	15.0
	U-500	RT	D	175,000	120,000	10.0	195,000	135,000	12.0
		1400	D	125,000	105,000	12.0	140,000	120,000	15.0
	M-252	RT	B	170,000	115,000	15.0	185,000	125,000	20.0
		1000	B	160,000	105,000	15.0	165,000	115,000	22.0

	ALLOY*	TEMPERATURE STRESS	GUARANTEED MINIMUM	TYPICAL VALUES
STRESS RUPTURE	Waspaloy	1350°F.—70,000 psi	70 hours—6% Elongation	130 hours—16% Elongation
	René 41	1350°F.—85,000 psi	30 hours—8% Elongation	60 hours—15% Elongation
	Astroloy	1800°F.—20,000 psi	20 hours—7% Elongation	35 hours—12% Elongation
	Udimet 500	1650°F.—25,000 psi	30 hours—6% Elongation	55 hours—12% Elongation
	M-252	1500°F.—40,000 psi	30 hours—8% Elongation	55 hours—16% Elongation

NOTE: The guaranteed minimums are based upon radial and tangential test locations.

COMPOSITION AND HEAT TREATMENT

	ALLOY*	ELEMENTS							
		C	Cr	Mo	Co	Ti	Al	B	Ni
CHEMISTRY	Waspaloy	.08	19.0	4.3	13.5	3.0	1.4	.004	Balance
	René 41	.08	19.0	10.0	11.0	3.1	1.6	.004	Balance
	Astroloy	.05	15.0	5.0	15.0	3.5	4.3	.030	Balance
	Udimet 500	.07	18.5	5.0	18.3	3.0	3.0	.003	Balance
	M-252	.15	20.0	10.0	10.0	3.0	1.3	.002	Balance

HEAT TREATMENT	A.	1850°F.—4 hours—OQ, 1550°F.—2 hours—AC, 1400°F.—16 hours—AC
	B.	1950°F.—4 hours—AC, 1400°F.—16 hours—AC
	C.	2100°F.—½ hour—AC, 1400°F.—16 hours—AC
	D.	1975°F.—4 hours—AC, 1500°F.—24 hours—AC, 1400°F.—16 hours—AC

NOTE: Refer to appropriate heat treat code in Tensile & Yield Strength table.

*Waspaloy: Pratt & Whitney Aircraft Corp.; René 41, Astroloy and M-252: General Electric Company; Udimet 500: Metals Division, Kelsey-Hayes Company.

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permits designing to higher operating stresses . . . increased efficiency . . . greater component reliability for every gas turbine application

Rapid progress in developing the gas turbine has materially extended application of this prime power source to areas other than aircraft. Significant contributions in forging techniques and metallurgical advancements by Wyman-Gordon have in part made this possible.

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WASPALOY

RENÉ 41

ASTROLOY

UDIMET 500

M-252

MEETING DESIGNERS' NEEDS IN EVERY TURBINE APPLICATION

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- Nuclear Power and Propulsion
- Rail and Highway Transport
- Power Generation
- Air Supply and Pumping
- Pipeline Boosting
- Auxiliary Service
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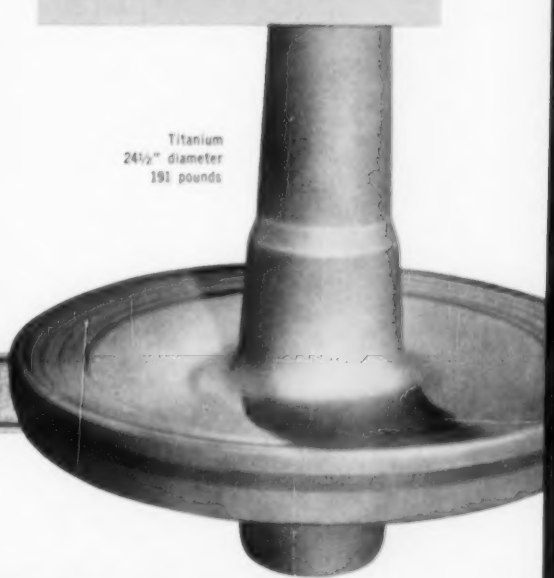
- Marine Propulsion
- Stationary Power



Titanium
24½" diameter
191 pounds

Titanium
15½" length

EST. 1883

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FORGINGS

of Aluminum Magnesium Steel Titanium . . . and Beryllium Molybdenum Columbium and other uncommon materials

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GRAFTON MASSACHUSETTS — LOS ANGELES CALIFORNIA — PALO ALTO CALIFORNIA — FORT WORTH TEXAS

PERSONALS

(Continued from page 591)

presented the Outstanding Young Engineer award for 1960 by the Engineering Society of Detroit. The award, conferred annually on an engineer under 30 years of age, is based on recommendations and record of achievement.

Robert S. Baker has been appointed vice president of manufacturing for The American Brass Co. He had been director of mill operations for American Brass since 1952.

Antoine Marc Gaudin, Richards Professor of Mineral Engineering, Massachusetts Institute of Technology, is the new chairman of the Engineering Foundation, dept. of the United Engineering Trustees Inc. (UET)

The Engineering Foundation acts as the research federation of UET's five constituent societies, which include the AIME.

Donald K. Work, director of research, New York University, was at the same time named director of the Foundation. Elected to the Foundation's Board of Directors was **A. B. Kinzel,** vice president—research, Union Carbide Corp.

A. James Kiesler was awarded an honorary degree by the University of Missouri School of Mines and Metallurgy during commencement exercises May 29th. A graduate of the Missouri School of Mines, Mr. Kiesler has been with the General Electric Research Laboratory since 1946. He is a member of the Conference Committee of the Electric Furnace Committee, The Metallurgical Society.

Thomas E. Ban has been elected vice president in charge of research, McDowell Co. Inc., Cleveland. He joined McDowell in 1955 as director of research.

Joseph E. Burke has been elected chairman of the Basic Science div., American Ceramic Society. The division is concerned with research and applications of modern technical ceramics. Dr. Burke is manager of the Ceramic Studies section, General Electric Research Laboratory.

Terrence E. Dancy, Irwin I. Bessen, Norman L. Samways, and **Harry W. Meyer** were involved in recent management changes in the research div., Jones & Laughlin Steel Corp. Dr. Dancy is now asst. director of research, and he will concentrate on process metallurgy. Dr. Bessen also has been named an asst. director of research, but his fields will be physical and mechanical metallurgy, chemistry, and product development. Dr. Samways is now research supervisor, and will direct research activities in steel processing. Dr. Meyer has been named research supervisor, and will direct research activities in blast-furnace and steelmaking processes.

Bruce S. Old is now senior vice president of Arthur D. Little Inc. Dr. Old has been a vice president since 1951. In his new position, he will remain in charge of the company's work in metallurgy and radio chemistry.

Robert I. Jaffee and **George K. Manning** have been named technical managers in the Dept. of Metallurgy, Battelle Memorial Institute. Both men will direct activities in the fields of process metallurgy, mechanical metallurgy, physical metallurgy, fabrication metallurgy, chemical metallurgy, and metallurgical engineering.

Robert E. Christian has taken over the post of general superintendent of the Bagdad operation at the West Leechburgh (Pa.) works of Allegheny Ludlum Steel Corp. The Bagdad facility, presently under construction, will process high-grade, grain-oriented silicon electric strip steel. Mr. Christian's most recent previous assignment was asst. to the works manager, special assignments, West Leechburgh works.

Kenneth G. Carroll addressed the American section of Société des Ingenieurs Civils de France on *The Castaing Microsonde, A New Approach to the Study of Metals,* at a New York meeting May 19th. Dr. Carroll is head of the Physics section, International Nickel Co.'s Bayonne, N. J., research laboratory.

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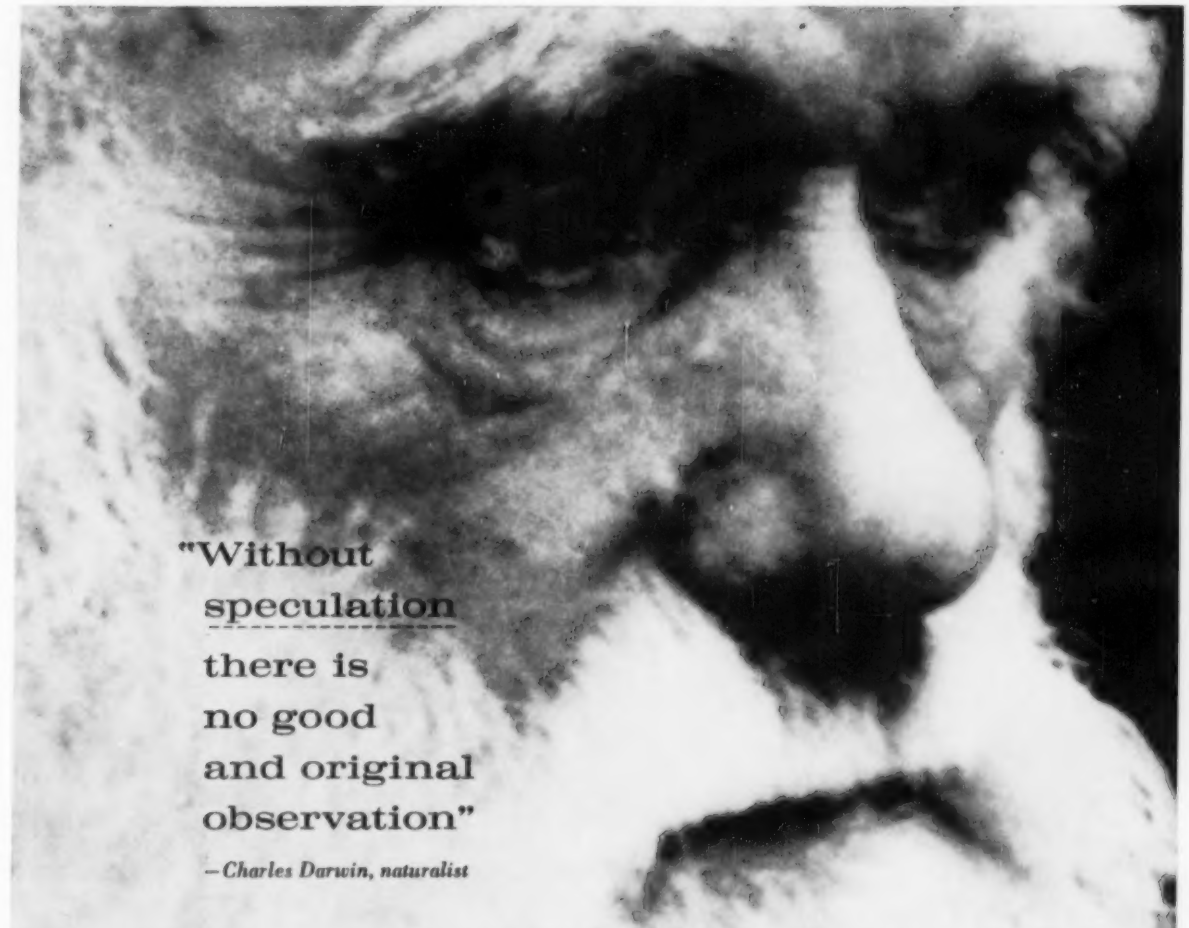


Man's search for scientific knowledge and understanding has its taproots in the above thought expressed by Darwin in a letter to his distinguished contemporary, Alfred Russel Wallace, in 1857.

Speculation—intuitive contemplation guided by past discoveries—led Darwin to his famous observations set forth in *Origin of Species*. Similarly, it led Alexander Graham Bell to the invention of the telephone—and has since led to many major advances in electrical communications.

At Bell Telephone Laboratories, the puzzling flow of current in semiconductors provoked speculation which yielded the transistor—and a Nobel Prize. Speculation about the behavior of the electron led to experimental proof of its wave nature—and another Nobel Prize. "Brains" capable of guiding missiles and space probes first took form in the bold speculations of Bell Laboratories scientists.

Today, Bell Laboratories scientists and engineers are more keenly aware than ever of the importance of speculative thinking. The far-reaching scientific and technological developments of tomorrow are already the subject of advanced research. Among them are radically new materials and devices—basically new switching systems, transmission via satellites, and waveguide networks able to carry hundreds of thousands of voices simultaneously.

Through informed speculation about Nature's laws, Bell Laboratories will continue to search for the "good and original observations" which are so vital to the ever-improving Bell Telephone System.

BELL TELEPHONE LABORATORIES

WORLD CENTER OF COMMUNICATIONS RESEARCH AND DEVELOPMENT

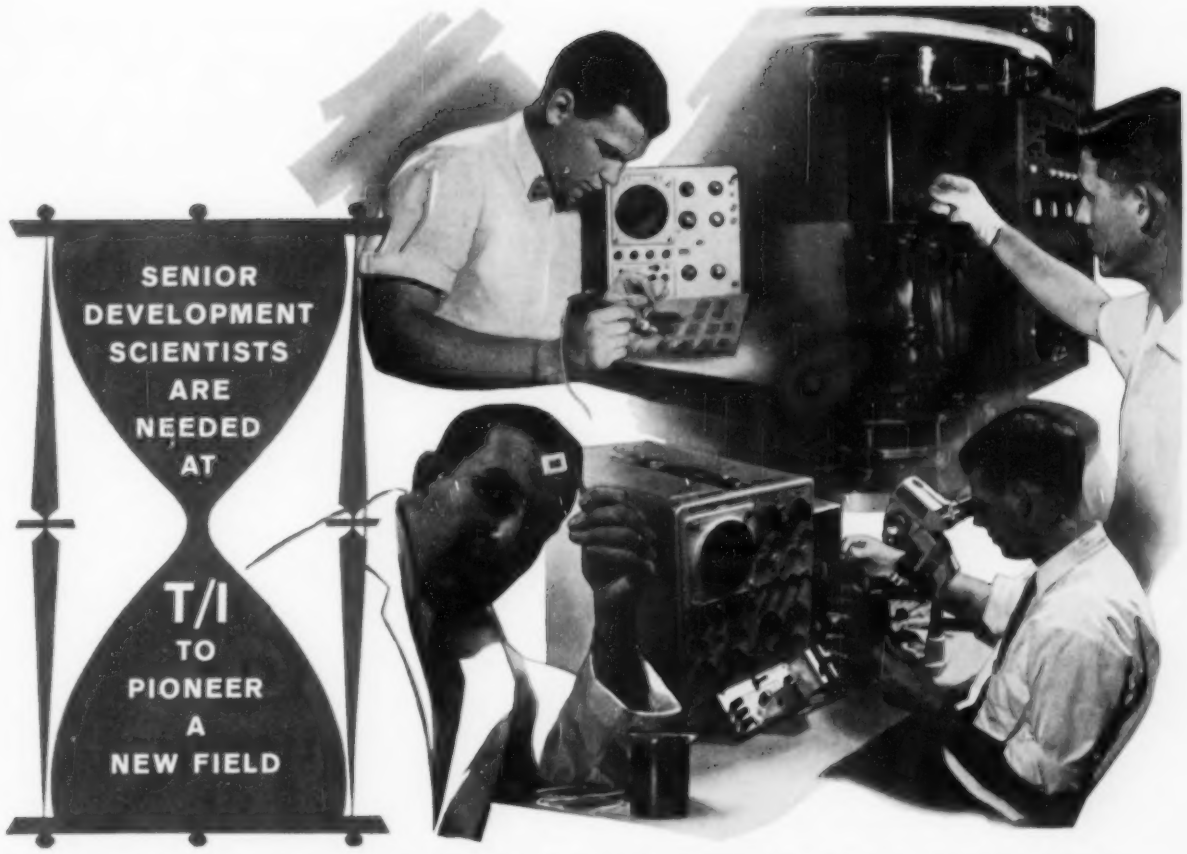
TRANSACTIONS
OF THE METALLURGICAL SOCIETY OF AIME

Contents of the August 1960, issue

The Development of Modern Copper Smelting—Charles R. Kuzell 578
New Tough Pitch Continuous Copper Melting and Casting Unit at Asarco's Perth Amboy Plant—G. D. Storm and J. R. Stone 584
The Precipitation of Carbon from Alpha-Iron I. Electromicroscopic Study—R. H. Doremus and E. F. Koch 591
The Precipitation of Carbon from Alpha-Iron II. Kinetics—R. H. Doremus 596
Self-Diffusion in Gamma Uranium—S. J. Rothman, L. T. Lloyd, and A. L. Harkness 605
Preparation and Properties of High Purity Scandium Metal—F. H. Spedding, A. H. Daane, G. Wakefield, and D. H. Dennison 608
X-Ray Studies of Polygonization and Subgrain Growth in Aluminum—R. J. Towner and J. Alfred Berger 611
Effect of Si and Al on the Stability of Certain Sigma Phases—K. P. Gupta, N. S. Rajan, and Paul A. Beck 617
Quantitative Addition and Recovery of Oxygen Isotopes in Niobium (Columbium)—W. F. Harris, W. M. Hickam, M. H. Loeffler, and D. H. Shaffer 625
Inverse Segregation in Aluminum-Zinc Ingots—W. V. Youdelis and D. R. Colton 628
A Mutual Solid Solubility Scale for Metals—Y. L. Yao 632
Observation of Slip, Twinning, and Cleavage in Iron-Phosphorus Solid Solutions—E. Hornbogen 634
The Gamma to Epsilon Transformation in Zr 20 to 70 Wt Pct U Alloys—A. A. Bauer 636
The Solubility of Lead in Liquid Iron—Arthur E. Lord and Norman A. Parlee 644
A Basket Cathode Electrolytic Cell for Production of Titanium Metal—W. R. Opie and O. W. Moles 646
Deformation Behavior of Zone-Melted Tungsten Single Crystals—H. W. Schadler 649
Environmental Effects on the Mechanical Properties of Ionic Solids with Particular Reference to the Joffe Effect—R. J. Stokes, T. L. Johnston, and C. H. Li 655
Stress Induced Twin Boundary Motion In AuCdβ' and β'' Alloys—H. K. Birnbaum and T. A. Read 662
Co-Rich Intermediate Phases in the Cb-Co System—Shozo Saito and Paul A. Beck 670
The Oxidation of Iron in Carbon Dioxide-Carbon Monoxide Atmospheres—W. W. Smeltzer 674
Kinetics of Grain Boundary Migration in High-Purity Lead Containing Very Small Additions of Silver and Gold—J. W. Rutter and K. T. Aust 682
The Evolution of Textures in Fcc Metals: Part I. Alloys of Copper with Germanium and Tin—Y. C. Liu and R. H. Richman 688
Effect of Heat Treatment in the Ferrite-Austenite Region on Notch Toughness of Low-Carbon Steels—W. C. Leslie, R. L. Rickett, and W. D. Lafferty 699
Gaseous Reduction of Fine Iron Ores in the Fluidized State—S. Y. Ezz 709
Growth of Chromium Coatings from Liquid Metallic Solutions—S. T. Wlodek and John Wulff 716
Constitution of Fe C Mo Alloys Containing 0.05-1.3 pct C and 0.03-6.0 pct Mo—R. F. Campbell, S. H. Reynolds, L. W. Ballard, and K. G. Carroll 723
Relationship Between the Mu Phase and the Sigma Phase in the Mo-Mn-Co System—B. N. Das and Paul A. Beck 733
Dislocations in Deformed Single Crystals of Alpha Brass. Part I: General Observations—J. D. Meakin and H. G. F. Wilsdorf 737
Dislocation in Deformed Single Crystals of Alpha Brass. Part II: Pileups—J. D. Meakin and H. G. F. Wilsdorf 745
The Isothermal Transformation of Eutectoid Beryllium Bronze at High Temperatures—Jack S. Brett, George L. Kehl, and Emilio Jaraiz F. 753

Technical Notes

Intermediate Phases with the Cu$_5$Ca Structure—S. E. Haszko 763
Dislocation Etch Pits in High-Purity Cadmium—J. H. Wernick and E. E. Thomas 763
Fabrication of Thulium Foil—H. H. Klepfer and M. E. Snyder 765
Grain Boundary Sliding Versus Grain Boundary Migration in Creep—N. R. Adsit and J. O. Brittain 765
The Deoxidation Equilibrium of Titanium in Liquid Steel—John Chipman 767
Self-Diffusion of Iron in Nickel Ferrite—R. H. Condit, M. J. Brabers, and C. E. Birchenall 768



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The need is for the scientist or engineer sufficiently experienced that he can explore this project from his own viewpoint and make immediate, significant contribution. Depending entirely on his own qualifications, he may either join a semiconductor network team — or he may take charge of such a group. The opportunity for leadership — whether immediate or in the future — is here.

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This — in actual size — is an interconnected stack of 11 semiconductor networks. *Solid Circuit* semiconductor networks are complete electronic circuits synthesized within a semiconductor material. By selectively diffusing and shaping conductance paths in this material, semiconductor networks have been designed to perform such circuit functions as amplification, switching, counting, pulse generation, etc. In addition to effecting a significant advance in microelectronics, semiconductor networks provide improved reliability and performance. This TI development is now producing devices which are being evaluated for satellite, missile and airborne applications.

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Materials Research Boosted by $13.9 M in Defense Contracts

The Advanced Research Projects Agency (ARPA) of the US Department of Defense has awarded three universities contracts totaling $13.9 million for research in materials. The recipients are the University of Pennsylvania ($4.4 million); Northwestern University ($3.4 million); and Cornell University ($6.1 million).

At the **University of Pennsylvania,** A. Norman Hixson, asst. vice-president for engineering (graduate studies) says, "The University expects to erect a three-story, 65,000-sq-ft building . . . to house the new facility. The balance of the funds will be used to equip laboratories and recruit the teaching staff and graduate students necessary to carry on the research.

The School of Metallurgical Engineering, which now has six professors, and 20 full-time and 23 part-time graduate students, plans to expand to a staff of 15 professors, 11 research associates, and some 72 full-time graduate students.

The solid-state group in the physics dept., now numbering six professors and 34 graduate students, will grow to 14 and 58, respectively.

The Chemistry dept. will increase from eight professors and 26 graduate students to 15 professors and 58 graduate students.

Materials research will be carried on with solids over a temperature range from less than 1°K to over 873°K. Research in the Metallurgy dept. will involve a study of the effects of microscopic defects on the properties of metals, alloys, and semiconductors. The structure of intermetallic compounds and other alloys, solid-solution strengthening, plastic deformation, fracture, and the control of structure and properties also will be studied.

Solid-state physics research will be concerned with thermal conductivity, ferromagnetism, ferroelectrics, imperfections, transport processes, magnetic phenomena in dilute alloys, photochemical processes, magnetic resonances, optical processes in the far ultra-violet, X-rays, internal friction, and the many-particle theory.

Chemical research will be devoted to diffusion in polymers, polymers under high pressure, solid-vapor reaction, photoconductivity, electron and X-ray diffraction, inorganic polymers, catalysis, electronic processes in oxides, and theoretical physical chemistry.

Northwestern will use its $3.4 million to help build, equip, and staff a new Materials Research Center. The Center will take the form of two wings on the University's 20-year-old Technological Institute. The wings will house most of the 18 specialized laboratories that will comprise the Center.

Chairman of the materials project will be Morris E. Fine, currently chairman of the school's Materials Science dept. Plans call for immedi-

(Continued on page 604)

MARKET DEVELOPMENT—REFRACTORY METALS

The entry of a progressive chemicals manufacturer into a new field has created an outstanding opportunity in the Market Development Department for a Metallurgist or Inorganic Chemist with 3-5 years experience in non-ferrous metallurgy (preferably refractory metals).

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Continuing a program of gradual expansion of facilities and personnel, the J&L Research Division is interested in employment inquiries from engineers who are considering an employment change now or in the near future. Plans have recently been approved to make a significant addition to laboratory and shop space within the next year.

Openings presently exist in the following areas: process metallurgy, physical metallurgy, metal working, corrosion, alloy development, electrical steels, ore beneficiation and agglomeration.

Inquiries are welcomed from men with Ph.D., M.S. or B.S. degrees, with or without industrial research experience. When it appears to be mutually desirable, interviews are arranged in Pittsburgh.

Excellent opportunity exists for professional development and personal advancement in the research field or in technical functions related to production and sales. Continuation of education through attendance at evening classes at Carnegie Institute of Technology and the University of Pittsburgh is encouraged by the J&L Educational Assistance plan.

If you are interested, send a complete resume in confidence to

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Alcoa starts new smelter

The first primary aluminum was poured from a potline at Aluminum Co. of America's new $80-million smelter in Warrick, Ind., recently. The potline is rated at 35,000 tons annually, while the total capacity of the facility is 175,000 tons annually. However, market demands will dictate the completion and use of four other potlines. Electric power for the Warrick works is being produced by one of three generating units at Alcoa's new 375,000-kw steam plant adjacent to the smelter.

Morocco plans steel industry

The government of Morocco has set its sights on a national steel industry as the beginning of the Country's industrialization. Morocco's Minister of National Economy, Abderrham Bouabid, made the announcement.

Site of the proposed steelworks is Ras Kebdana, which lies on the Mediterranean coast between Nador and the mouth of the Moulouya river. The plant is expected to start production in 1962 with an initial rate of 165,000 tons of rolled products annually; by 1968, a yearly output of 245,000 tons of steel and 20,000 tons of ferro-manganese is envisaged.

Iron ore will come from deposits in the Rif mountains, where there are proved reserves of 25 million tons and an expectation that they are much greater. Fuel will be obtained from the extensive anthracite deposits at nearby Djerrada. Since January 1959, the Moroccan government has been talking with Republic Steel Corp. and National Lead Co. about the possibility of using the RN direct reduction process. It is hoped ultimately to use natural gas from the Sahara to produce cheap electricity.

National Carbon gets $12 million

Wright Air Development div. of the US Air Forces Air Research and Development Command has awarded a $12 million, three-year contract to National Carbon Co., div. of Union Carbide Corp. The contract is for research and development of graphite for missile and space vehicle components.

Work under the contract will be carried out at a soon-to-be-constructed Advanced Material Laboratory at Lawrenceburg, Tenn. The Laboratory will consist of a raw materials plant, a pilot processing plant, a completely-equipped laboratory, and an office and services building.

The research program will explore raw materials and processing techniques that will 1) significantly reduce the variation in mechanical and physical properties to about one-third that now found in the best grades of graphite; 2) reduce the total manufacturing time for graphite from many weeks to several days; 3) achieve the foregoing objectves for pieces larger than 3 ft in diam by 6 ft in length; and 4) develop a processing facility to produce such graphites in quantity sufficient for proper evaluation under full-scale conditions.

Alloy has low thermal expansion

An iron, nickel, and cobalt alloy, called *Fernico-5*, is said to have the thermal expansion of alumina. Developed by the General Electric Research Laboratory, the alloy is expected to find use in metal-to-ceramic seals. The thermal expansion of alumina is much lower than that of the metals and alloys normally used in metal-to-ceramic seals. Thus, it has not been possible for the electrical industry to take full advantage of the high strength, high heat-resistance, and excellent insulating properties of alumina. "We now have an inexpensive and easily fabricated alloy that will enable us to use alumina in such products as electron tubes, thermionic energy converters, capacitors, switchgear, and high-temperature circuits—all of which require ceramic-to-metal seals, so explains Guy Suits, GE vice president and director of research. The alloy's development is also expected to advance applications of *Lucalox*, a translucent ceramic announced by GE late last year.

Thermoelectric generator built

A 5-kw thermoelectric generator— 50 times more powerful than any previous thermoelectric power plant—has been developed by Westinghouse Electric Corp. The generator was built for the Bureau of Ships, US Navy.

Although its thermoelectric metal components were not revealed, they are thought to be bismuth, tellurium, and other semiconductor metals.

The new generator was built from thermoelectric assemblies, or modules, which can be arranged electrically to give a wide range of output voltages and currents. The modular construction also gives versatility in physical design, permitting the generator to be built as two identical sub-generators. The thermoelectric portion of each 2500-w sub-generator resembles a hollow cylinder about 30 in. in diam and 30 in. high. The thermoelectric modules form the walls of the cylinder. The walls' inner surfaces are exposed to the flame of burning kerosene, while the outer surfaces are cooled by water piped to them.

Further details on the thermoelectric power program are given on pp. 615-619 of this issue, which includes a detailed survey *of Metallurgy in the Navy*, as presented at this year's AIME Annual Meeting.

Energy Thermionic conversion 14 pct

The Radio Corp. of America recently unveiled a thermionic energy converter with up to 14 pct efficiency. The electronic tube is said to be capable of generating either direct or alternating current at a wide range of frequencies. The converter has operated at 2012°F, according to H. W. Leverenz, director of research at the Corp.'s Princeton, N. J., laboratories. Previous electronic tubes like this had operated at acceptable efficiencies only at temperatures well over 3632°F, he explained.

The tube's development is part of a research program being undertaken for the Air Force's Cambridge Research Center.

REPORTER

REPORTER

Alloy developments . . .

Cr-Ni—An alloy with proved service up to 2300°F has been announced by Electro-Alloys div., American Brake Shoe Co. Named *Supertherm*, the alloy is composed of 26 pct Cr, 35 pct Ni, 0.50 pct C, 0.70 pct Mg (max), and 1.60 pct Si. The composition is strengthened and stabilized with cobalt and tungsten.

Al-Fe-Ni—Aluminum Co. of America has announced development of aluminum-iron-nickel alloys which withstand the deteriorating effect of high-purity water at nearly 700°F. They hold promise as cladding materials for uranium fuel rods in the more powerful atomic reactors.

Both wrought and APM (aluminum powder metallurgy) alloy forms were tested. An APM alloy containing 4.81 pct Fe and 7.03 pct Ni recorded the best results.

Cb-Ti-Mo—*D31*, a columbium alloy that contains 10 pct Mo and 10 pct Ti, is one of the most promising high-temperature alloys, claims the du Pont Co. developers. Thompson-Ramo-Wooldridge cooperated in the alloy's development.

The alloy is said to have fairly good ductility at room temperature; tensile strength of 34,500 psi; resistance to thermal shock; and reasonably good resistance to oxidation at high temperatures. The Cb-Ti-Mo alloy is produced in vacuum by a consumable electrode arc melting process. It can be worked by forging, swaging, or rolling.

Cu-Ni-Si—The American Brass Co. has brought out *Cunisil-837*, an alloy of 97.5 pct Cu, 1.90 pct Ni, and 0.60 pct Si. Its properties are said to be high strength and corrosion resistance. The alloy is destined for electrical equipment and other uses.

Cb-U—A columbium alloy containing 20 pct U was recently touted as the metallic fuel for small-size nuclear reactors of the future. J. A. DeMastry, Battelle Memorial Institute, made the prediction in a paper read for its authors, F. R. Shober and R. F. Dickerson, before the American Nuclear Society.

Backing Mr. DeMastry's prediction of use in future compact and gas-cooled reactors in which high operating-temperatures are necessary is the alloy's good tensile strength and hardness up to 1600°F. The alloy also is said to retain fission gases; and has high thermal conductivity and good corrosion resistance.

Direct stainless steel

A major break in the Strategic-Udy picture—and news we've been expecting for several years—is the announcement that the Strategic Materials Corp. and Universal-Cyclops Steel Corp. have signed an agreement for the joint development of the Udy smelting procedure for the production of stainless steels and high-temperature alloys from lateritic and low-grade chromite ores. The economics of utilizing an abundant raw material to produce a high-price product are at once obvious and more interesting economically than anything that Udy has heretofore attempted. The immediate result of the agreement is a $1.5-million addition to the pilot plant of Strategic Materials at Niagara Falls, Ontario, Canada.

Ceramic-graphite material

Boeing Airplane Co.'s Aero-Space div. is experimenting with a ceramic graphite-base material that spontaneously forms its own protective coating against heat and oxidation.

The maximum tension and compression capability of the material is said to be about double that of standard graphite at room temperature. It also has a strength advantage above 3000°F .The protective layer develops at about 2200°F, appearing in one composition as a smooth, adherent, non-porous, yellowish-brown film about 0.001 in. thick. As temperature and exposure to oxidation increase, the layer thickens and becomes more resistant. Ultimate thickness depends on the combination of time, temperature, and oxidation.

A typical composition consists, by weight, of 59 pct graphite, 24 pct molybdenum disilicide, and 25 pct titanium boride, plus minor ingredients to promote bonding.

Three Mn producers expand

Entry of a third producer of electrolytic manganese in the US, plus the expansion of its two predecessors, is in the news. American Potash & Chemical Corp. is the new entry with the contemplation of a $5-million plant at Aberdeen, Miss. When completed in late 1961, its initial capacity will be 10 million lb annually. American Potash also is an electrolytic manganese-dioxide producer at Henderson, Nev.

Meanwhile, Foote Mineral Co. expects a 20 million lb per yr increase in electrolytic manganese when it completes a Johnsonville, Tenn., plant. However, Foote's will be a two-stage project, with the first unit—to produce 10 million lb per yr—going on stream in late 1961 or early 1962. A total outlay of $6 million is anticipated.

Union Carbide Metals Co.'s expansion is already a reality. The company announced a 20 pct increase in production capacity with the installation of more cells at its Marietta, Ohio, plant.

Mn-Mo steels developed

Application of manganese and molybdenum in two austenitic steels has been announced by Climax Molybdenum Co., div. of American Metal Climax Inc. They are said to provide improved abrasion-resistance in castings. A 12-2 Mn-Mo alloy is said to have 40 pct longer life and resistance to flow than Hadfield manganese steels. The other, a 6-1 Mn-Mo alloy, shows promise for grinding mill liners and scoop lips, screen decks, grates, and jaw crusher liners. Climax Molybdenum does not intend to market the steels commercially, but will make its research and development information available on request.

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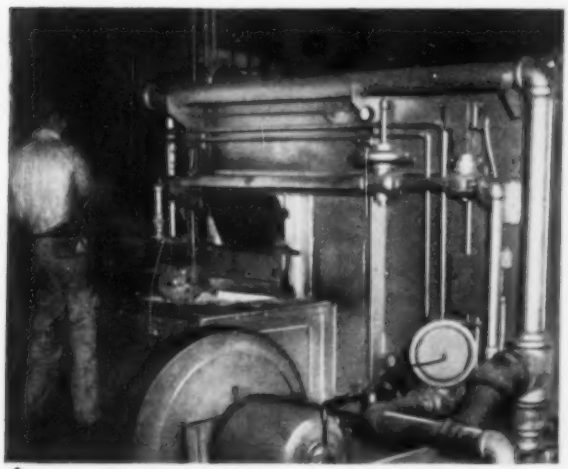
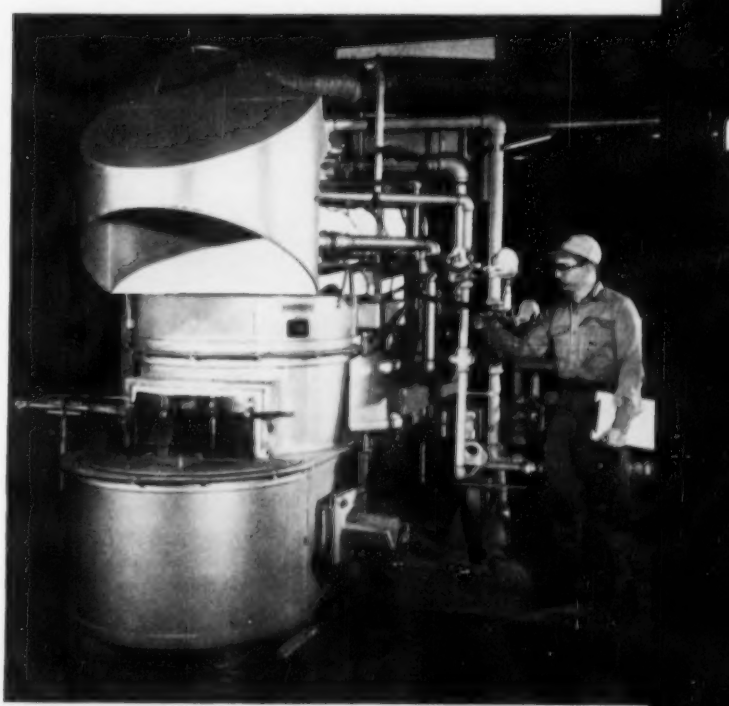


This double chamber dry hearth furnace was tailored to the specific needs of Eastern Castings Corporation, Newburgh, N. Y. It is used for permanent mold aluminum casting at temperatures up to 1550°F. For this high-temperature application, structural steel was moved to the outside of the shell and insulation was increased to accommodate the higher temperature. The user reports continuous, high production at tremendous savings on maintenance. ***For more information, please send for Bulletin 594.***



This dry hearth melting and holding furnace is used for many different aluminum alloys at Manufacturing Research, International Harvester Company. It is gas fired, has a melting rate of 750 pounds per hour and a holding capacity of 1,000 pounds. The pit beneath the pouring spout enables the company to pour castings as large as the holding capacity of the furnace. ***Request Bulletin 594.***

Dollin Corporation, Irvington, N. J., has purchased this cradle tilting reverberatory furnace for breaking down and holding aluminum. It handles a larger volume of metal at lower cost than the furnaces it has replaced. There is also a better balance of heat, resulting in cleaner metal. Working conditions are cooler near the unit, and its design provides for easy drossing. ***Please write for Bulletin 691.***

SIXTH VOLUME

ON

NUCLEAR METALLURGY

Papers at a Symposium on
Effects of Irradiation on Fuel and Fuel Elements

Conducted by

INSTITUTE OF METALS DIVISION

The Metallurgical Society
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November 4, 1959
(Fall Meeting of The Metallurgical Society of AIME, Morrison Hotel, Chicago)

Fundamentals of Fission Damage	by J. A. Brinkman
Swelling and Fission Gas Agglomeration in Metal Fuels	by A. T. Churchman
Fundamentals of Inert Gas Agglomeration and Swelling in Metals	by R. S. Barnes
Operational Performance of Bonded and Unbonded Uranium Fuel Rods	by T. T. Claudson, G. T. Geering, J. W. Goffard, and J. E. Minor
Irradiation Behavior of U-FS and U-PU-FS Fast Reactor Fuels	by J. A. Horak and J. H. Kittel
Crystallographic Study of Radiation-Induced Recovery in Cold-Worked Uranium	by D. Tardivon
Irradiation Behavior of UO_2 Fuel Elements	by J. A. L. Robertson, A. S. Bain, G. M. Allison, and W. H. Stevens
The Swelling of UO_2 at High Burnup	by W. K. Barney
Irradiation Testing of Plutonium-Uranium Oxide Nuclear Fuel	by J. L. Bates and W. E. Roake
Irradiation Behavior of ThO_2–UO_2 Fuels	by L. A. Neimark and J. H. Kittel
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editorial

Are We Fostering Creative Research?

"How can young research scientists and engineers be brought more stimulatively, and creatively into contact with the frontiers of science and technology in such a way as to accelerate significant discovery . . .?" Such was a question posed a recent conference on *Research Goals* sponsored by the National Science Foundation and held in cooperation with 15 leading scientific and engineering societies, including the AIME.

Scientific and technological progress would be greatly accelerated if conditions more favorable to achieving bold, imaginative pioneering in basic research and in technological innovations could be realized. But such conditions are not readily achieved today.

Modern research requires the amassing of enormous amounts of detailed scientific and technological knowledge. However, in this gathering process research people run the risk of becoming preoccupied with goals of relatively small dimensions which, by their very nature, hold little promise of leading to significant discovery. Furthermore, there are many forces acting upon the young researcher which cause him to veer in the direction of conservatism. These forces being in formative education and continue through the doctoral thesis; they are inherent in the way in which research is structured and supported; and they are reflected in the rigidity of scientific and engineering societies. YES, engineering societies, that is what the conference said.

So, what is to be done? How can we, as members of an engineering society, provide a stimulus to the high degree of creative originality needed today? For this the conference had some suggestions which it might be well for us to consider.

First, encourage the presentation and publication of papers of a philosophical nature which look to the future of science and technology. An individual can report on completed research, but if he attempts to speculate about the future, he may find himself regarded as a charlatan.

Second, establish more effective practices for increasing the attendance and participation of talented, young members at meetings.

Third, develop comprehensive programs for digesting the *state of the art*. Young people are confused by the disorganized state of research knowledge.

Fourth, establish meetings for the purpose of developing a more effective interchange of ideas between scientists and engineers in research areas of mutual interest. Engineering societies have confined themselves too much to areas in which scientific and technological principles have *proven* utility.

Fifth, establish free forums at conventions where any member may make a short presentation of his creative work . . . allowing the widest latitude of subject matter . . . with no publication requirement, except in abstract form.

Let's take out a score pad. How does The Metallurgical Society fare on these five points? Are we doing all we can to foster the creative research so desperately needed by our Country today?

FWS

MATERIALS RESEARCH . . .

(Continued from page 598)

ate increases in both staff and graduate students. An increase to 55 —double those now engaged in materials research—is anticipated in the next five years. Graduate student participation in the area will jump 2½ times to 175.

Cornell also will call its materials facilities a Materials Science Center. Work at the Laboratory of Atomic and Solid-State Physics will take the brunt of the Center's initial activity. Later, the Metallurgical Engineering and Engineering Mechanics and Materials depts. will become equally important.

About one-sixth of the work in metallurgy will be devoted to intermetallic compounds, freezing, transformations, solid-solution strengthening, nucleation, plastic deformation, fracture, and properties of and phenomena in iron-base alloys.

Work in mechanics and materials will deal with elastic constants as functions of pressure, ferroelectrics under impulse loading, and diffusion and creep under hydrostatic pressure.

Cornell's new Laboratory of Atomic and Solid-State Physics will be concerned with imperfections, transport processes, magnetic resonances, internal friction, photochemical processes, surface phenomena, ferroelectrics, magnetic phenomena in dilute alloys, optical processes in the far ultra-violet, X-ray, cooperative phenomena, ferromagnetism, thermal conductivity, and the many-particle theory.

The Center's chemistry emphasis will be on electron and X-ray diffraction, inorganic polymers, solid-vapor reactions, electronic processes in oxides, diffusion in polymers, polymers under high pressure, catalysis, photoconductivity, and theoretical physical chemistry.

A substantial part of Cornell's $6.1-million contract will go into research equipment, including about $700,000 for individual research projects and $1.2 for common facilities.

Each of the university's grants covers the first four years of its materials research program.

Electric Furnace Meeting at Chicago Nov. 30-Dec. 2

A total of nine technical sessions has been planned for the 18th Electric Furnace Conference, sponsored by the AIME, at the Morrison Hotel, Chicago, Nov. 30-Dec. 2.

The sessions will be held Wednesday and Thursday, Nov. 30th and Dec. 1st, with Dec. 2nd devoted to a choice of plant tours of the South Works, U. S. Steel Corp., or Lemont Manufacturing Corp.

Session I will take up Non-Metallic Inclusions in Steel; Session II is headed Factors in Improving Steel Quality; and Session III is to consider Control of Non-Metallics in Steel for Castings.

Session IV will be devoted to Some Developments in Steelmaking Processes, while Session V will deal with Refining Metal in Air Induction Melting. Session VI is entitled Manufacture of Carbide and Phosphorus; Session VII will be on Stainless Steel; Session VIII will take up New Developments (in castings); and Session IX will be on Manufacture of Ferro-Alloys.

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METALLURGY

From the first of a series of The Metallurgical Society's symposia on Defense Materials Problems, JOURNAL OF METALS *proudly presents, METALLURGY IN THE NAVY. Unfortunately, space prevents publication of all the papers delivered at the symposium in one issue, but additional papers will be found in future numbers. Theme of the symposium, A New Navy Requires New Materials, is illustrated in the articles which follow.*

1. The Navy's R&D Program

An overall summary of the Navy's Research and Development Program in metals and alloys, ceramics, and related materials.

by Julius J. Harwood

The Navy's R&D Program cannot be considered as a separate entity. It is a component—and we believe a vital one—of the overall materials research and development program of the Department of Defense, and in a broader sense, of the National effort in this field. The planning and conduct of Navy programs are not done *in vacuo*. There is a conscious realization of work performed elsewhere, and a deliberate effort is made to cooperate and coordinate with other agencies of the Department of Defense and Government at large, and as much as possible, with industrially-and privately-supported research. Thus, program gaps or deemphasis may exist, not only for technical reasons, but because research performed elsewhere is recognized.

The prime objective of the Navy R&D Metallurgy program is to make available materials with those properties required for the successful performance of naval weapons systems and the related vessels, equipment, components, hardware, etc. We attempt to meet our objective with a three-phased attack. At its base is a program of basic research in metallurgy and ceramics—more broadly, the science of materials—which aims at increasing our understanding of the relationships between micro structure and properties. With such research we hope to establish a solid background of information, thus enabling a more rational approach to alloy development and a more confident prediction and better understanding of the behavior of materials under service conditions. Closely related to the basic research effort is an applied research program in which there is immediate concern about improving available alloys or developing new alloy systems and related processing operations to meet specific target properties. These studies may be related to specific end items or, as is more often the case, to a broader range of operational requirements. The third phase consists of a development, test, and evaluation program which covers the selection, design, and prototype testing of materials and components—materials engineering.

These three efforts, and particularly the first two, are not sharply separable; indeed, one of the virtues of the Navy's coordinated program is the degree of interaction which exists between the basic and more applied research activities.

The responsibility for basic research primarily rests with the Office of Naval Research (ONR), but, as appropriate, certain areas of programmatic research and development work may be entertained

JULIUS J. HARWOOD is head, Metallurgy Branch, Office of Naval Research, Department of the Navy, Washington, D. C. This paper was presented at the 1960 AIME Annual Meeting.

IN THE NAVY

J. J. Harwood

by the Office. The applied research and development programs are conducted by the material bureaus of the Navy, e.g., Bureau of Naval Weapons, Bureau of Ships, Bureau of Yards and Docks, but they also have the option of engaging in exploratory research activities.

The following are the major research and development programs in metals and ceramics currently receiving attention by the Navy:

Structural materials

The objective of the structural materials programs is to improve the structural properties of available alloys or the development of new and improved alloys for specialized naval applications. The operating temperature spectrum of the materials in this grouping ranges from subzero temperatures to about 650°F. Analysis of current programs indicates that —in contrast to former years—only minor applied research support exists for aluminum, magnesium, copper, and other conventional nonferrous metals and alloys, except as needed for special applications. This is a direct reflection of our research's orientation toward the support of more advanced naval systems involving more aggressive environments and higher temperature operations.

Although consideration of steels for conventional shipboard machinery and structural components continuously prevails, emphasis is being placed on the use of high-strength steels for deep-diving submarine hulls. The need exists for steels or other alloys of yield strengths in excess of 150,000 psi capable of being produced, fabricated, and welded in thick sections. Weldability is a most important criterion, and resistance to explosive loading conditions is mandatory. Studies are underway on the influence of metallurgical structure, composition, and impurities on the properties and fabricability of appropriate steels. The factors influencing the weldability characteristics and the properties of weldments of such high-strength steels, particularly in thick sections, are receiving special attention.

A related program involves the development and evaluation of higher-strength steels for supersonic aerial vehicles, missiles, and rocket chambers. In contrast to the submarine program, we are concerned here with steels in thin gages, with yield strengths exceeding 240,000 psi. Weight saving in the intended applications is of paramount importance, with weldability and notch sensitivity characteristics of weldments again of significance. Brittle behavior (premature failure) under multiaxial loading and notch conditions are major problem areas. Much of the research in this area is aimed at the control of chemistry, structure, and fabrication history to ensure adequate ductility at high strength levels. The effects of surface treatments, e.g., plating and cleaning, on hydrogen embrittlement are being explored. Development and investigation of new steel compositions, high-strength welding electrodes, new fabrication methods (e.g., ausforming), and new construction methods (sandwich, stripwinding, etc.) constitute important program phases. Similarly, new design concepts involving the relationships between the load-bearing capacity of high-strength steels and minimum ductility limits for satisfactory service operation are being investigated.

Titanium alloys are being considered as competitive to alloy steels in both ship and aerial vehicle applications, but the effort—under direct Naval support at this time—primarily consists of evaluation, engineering, and design. Minor activity is continuing on conventional nonferrous alloy systems for a variety of shipboard applications but, again, this almost exclusively consists of evaluation and testing programs.

In the foreseeable future, research and development emphasis will involve: a) continuing programs on high-strength steels, with attention to weldability, fabricating, and new design concepts; b) a more intensive investigation of titanium for submarine hull, hydrofoil, and related applications, particularly if the price of finished shapes decreases; c) serious consideration of beryllium and its alloys as structural materials, depending upon the results of current Government research and development programs; and d) the introduction of composite materials and structures of a wide range of alloy systems, involving fine particle strengthening, fiber and flake metallurgy, thin film technology, etc.

Materials for 650°-1500°F

Again, in contrast to prior years, it is worth noting that relatively little direct alloy research and development is being supported in the areas of metallurgical activity falling within this category. Most of

the emphasis is on fabrication, weldability, and evaluation of commercially-available or previously-developed experimental alloys.

The largest single effort is the Titanium Alloy Sheet Rolling Program, which is being administered by the Bureau of Naval Weapons for the entire Department of Defense. This program is so well known and nationally-recognized that only the objective need be pointed out at this time: the development of manufacturing techniques for commercial production of titanium alloy sheet with increased uniformity, reliability, strength, weldability, and fabricability characteristics. This program is now entering into its final stages of evaluation of alloy components and design data. However, a similar sequence of operations has been initiated for promising experimental alloys of titanium with improved higher temperature strengths. Only a small amount of other metallurgical research on titanium alloys is currently supported by the Navy, in sharp contrast to the heavy emphasis during the 1950-1957 period.

The considerable effort underway on beryllium is directed primarily toward its use in hypersonic and re-entry vehicles. Some physical metallurgy and alloy development activity is going on, particularly with respect to the preparation of high-purity beryllium and the effect of impurities upon ductility and mechanical properties. However, much of the program is concerned with the engineering evaluation of available beryllium sheet and the fabricability of finished shapes.

Vanadium alloy research is receiving attention, and some emphasis can be noted in the problem areas related to the use of alloy steels for high-temperature steam systems (1250°F) and of materials for pressurized water reactors. Available materials for steam tubing, valves, bolts, boiler, and super heater components exhibit satisfactory performance at 1050°F. Problems are anticipated, however, for long-time shipboard operation (> 100,000 hr) with a 200° rise in operating temperature.

Future activity calls for the following: a) the DOD Titanium Alloy Sheet Rolling Program will be continued, as will a modest titanium alloy research program, particularly to improve high-temperature capabilities; b) more intensive investigation of high-strength steels for operation in the 1000°-1500°F temperature range will be conducted; c) depending upon the successful outcome of current R&D effort on beryllium, a major expansion of beryllium alloy activity may occur; and d) composite materials will be receiving increased attention.

High-temperature materials (1500°-2000°F)

Until just a few years ago, one of the major phases of the Navy high-temperature materials program was concerned with the nickel, cobalt, chromium, Ni-Co-Cr-Fe alloys—the so called *super alloys*. With the change in military emphasis from jet engine technology to ballistic missile and re-entry vehicles, there has been less work on the metallurgical aspects of these super alloys. Strong opinion today holds that only marginal improvements in the high-temperature capabilities of these alloys can be expected; consequently, except for some chromium-base alloy studies, little alloy work is underway in this area. However, as part of a more general program for the investigation of improved strengthening mechanisms, dispersion strengthening and matrix ordering of nickel-base alloys systems are being studied.

The relatively disappointing accomplishments of 10 years of research and development of cermets for structural applications has resulted in little current interest in them, other than for special rocket nozzle applications.

Except for the evaluation of currently-available materials for shipboard gas turbine applications, the priority attached to the solution of super high-temperature materials problems has served to rule out any major amount of work on conventional super alloys within the immediate future. This change in emphasis represents one of the most dramatic changes of the Navy R&D Metallurgy Program to occur within a relatively brief period. It reflects unusual responsiveness and flexibility of program planning to the rapidly advancing military technology.

Super high-temperature materials (>2000°F)

The aggressive operating environments and extreme high temperatures associated with ballistic missiles, re-entry vehicles, hypersonic craft, rockets, new fuels, and advanced propulsion systems have presented a fantastically complex set of materials problems which require urgent solutions. The temperature spectrum for such materials ranges from about 2000°F to over 5000°F. The current Navy R&D Program in this area is based on refractory metals and alloys, ceramics, graphite, and materials for thermal protection systems.

The Navy refractory alloy program is presented in detail in the paper by T. F. Kearns and J. Maltz. I would only note here that it is most comprehensive in scope, ranging from the preparations of high-purity materials and methods of consolidation to alloy development (Mo, W, Ta, Cb, Re, Cr, and Pt), physical metallurgy research, fabrication and sheet rolling, coating and oxidation protection, evaluation, design, engineering, and component testing.

The high melting points and thermal stability of oxides and other ceramic materials have focused attention on the potential use of ceramics as super high-temperature structural materials and insulating materials.

Because of ceramics' potential in radome and guidance applications, rocket nozzles and related propulsion components, and structural members, much attention is being paid processing and fabricating techniques. In addition to conventional slip casting, extrusion, rolling, and hydrostatic pressing are being investigated. These studies are supported by a strong research program on deformation and fracture characteristic of single crystal and polycrystalline ceramic materials and on physical ceramics. Various coating and deposition techniques and materials also are being investigated for thermal insulation and surface protection, e.g., arc spray coatings, plasma jets, thermitic ceramics, etc. The preparation, processing, and properties of ceramic fibers—glass, silica, and oxide fibers—also are being investigated for their incorporation into composite materials.

Graphite has become an important missile and rocket material. Surface protection techniques are being explored, as are new production methods for the preparation of improved graphites with reproducible missile-grade quality. It is necessary to emphasize those properties which either delay the

temperature rise or lower the temperature generated in the material by its environment. Such properties as thermal capacity, emissivity, thermal conductivity, and thermal expansion assume new importance, and a program for the generation of thermophysical data on a variety of materials is underway.

There exists sharp recognition of the importance of thermal protection systems involving heat alleviation schemes, such as, ablation and sublimation coatings; transpiration, film, or liquid metal cooling; and heat sinks and insulating layers to prevent the heat flux from penetrating to the primary structure.

Thermal protection systems emphasize the fact that no single material has the range of complex properties associated with many high-temperature applications. Therefore, composite materials and structure are being developed. Reinforced plastics and honeycomb sandwich constructions are conventional examples; others range from pure metals containing finely-dispersed oxide particles to ceramics containing metal fibers and meshes. Because of the attractive thermal properties of beryllium and beryllium oxide, various combinations of BeO with refractory metal fibers and BeO with oxides and carbides are being intensively investigated, as is the whole family of beryllides. Glass fiber reinforced metals and refractory metal fiber reinforced metals show considerable promise. The new field of *fiber metallurgy* is receiving considerable attention.

Closely related is the work on fine particle strengthening. The sintered aluminum powder concept is being extended to a variety of high-melting-point metals with striking results. There appears to be hope for developing new types of simple alloys capable of exhibiting thermal and mechanical stability at temperatures approaching their melting points. Also in the picture are simple or complex multilayer composite construction materials. Attempts are being made to take advantage of the extremely high strengths of metal and oxide whiskers and metal films.

Emphasis will continue on refractory alloys, thermal protection systems, and composite materials. Improved ceramic materials exhibiting superior insulation characteristics will receive greater attention, and the field of intermetallic compounds for structural and related applications most likely will involve substantial program effort.

Corrosion and environmental resistance

By virtue of its major operating environment, i.e., the sea, corrosion historically has been a field of major importance to the Navy. More advanced types of operations and weapons systems have superimposed upon marine corrosion a host of surface damage phenomena. Indeed, surface protection, in a general sense, is the key to many of our materials problems, particularly at high temperatures.

The Navy's investigations range from fundamental electrochemical and adsorption research to the evaluation of proprietary protection systems, with the prime objective being improved means of retarding deterioration of materials and equipment. Current emphasis is on the nature and protection of important corrosion reactions, such as cavitation damage, stress corrosion cracking, liquid metal attack, and high temperature water and pressurized steam attack.

A major program is underway involving anode and shielding studies, current distribution analyses, and the development of practical cathodic protections systems containing energized or *sacrificial* anodes. A variety of metal and ceramic coating systems are being investigated, as is the development and evaluation of anti-corrosion, anti-fouling paint systems. Marine fouling, borer attack, and marine deterioration also receive attention. There is a strong supporting research program on the kinetics and mechanisms of corrosion reactions, with particular interest on the relationships between metallurgical and defect structure and surface reactivity.

Fabrication and processing

The introduction of higher-strength and less-conventional types of materials exhibiting lower ductility properties than customary requires appropriate attention to fabrication and processing problems.

Weldability is of special importance, and the welding program is aimed at evolving fundamental information and developing and evaluating new techniques and procedures for the fabrication of high-strength, high-temperature and corrosion-resistant materials. A major effort is directed toward the evaluation of factors which determine the performance of weldments for hull structures, particularly under conditions of explosion loading. Effects of composition, mechanical properties, and plate thickness on weldability and notch toughness are being explored in considering hull construction for deep-diving submarines and thick steels for pressurized water-reactor construction. New or special welding techniques are being investigated, i.e., automatic welding procedures, ultrasonic welding, plasmatron and electron beam welding, and *electro slag* machine-type welding. Development of improved electrodes for welding high-strength steels also is underway.

Brazing and joining also are receiving special attention, particularly for the application of high-strength titanium alloys and steels. A variety of bonding systems are under investigation, including adhesive bonding exothermic ceramic brazing, metal polymer combinations, etc.

Castings historically have been employed by the Navy for ordnance and shipboard applications, and programs for evolving new techniques and procedures for the solution of casting problems have had long standing. The major effort now is on the development and evaluation of high-strength, shock-resistant, reliable castings for ship hull and machinery application and for non-magnetic (mine sweeper), corrosion resistant, and wear applications. Shell molding, precision molding, and vacuum degassing are receiving special attention. Because of the ever present potential of castings for critical naval application in advanced weapons systems, preliminary consideration is being given to the establishment of a coordinated and integrated research and development program leading to the ultimate production of high-quality castings.

The increasing application of high-melting-point alloys and their attendant processing difficulties has directed attention to the investigation of new forming and fabrication procedures, such as explosive forming, controlled atmosphere facilities for hot working refractory metals (*InFab*), and ausforming.

Investigation of improvements in non-destructive testing methods remains a constant program component.

Energy conversion, transmission, storage

The problems of guidance and detection of military vehicles, and the need for new types of power and energy conversion systems, has focussed a major share of our research attention upon the electronic transport properties and behavior of solids and upon solid-state devices. Certainly this area has achieved a stature equal to the problems of developing improved structural materials.

Energy conversion systems and, particularly thermoelectric power materials, comprise one of our major programs. It is interesting to note that this represents a field requiring the common attention of metallurgists, solid state physicists, and chemists in view of the types of semiconducting materials being investigated, i.e., intermetallics, mixed-valency oxides, doped carbons, sulfides, nitrides, and even organic compounds.

Magnetism and magnetic materials also have a long-standing research history in the Navy. There is a substantial program on the development of new materials and processing methods to improve existing materials for magnetic components used in ordnance, navigational, control, and communications systems. The development of magneto-hydrodynamic propulsion systems requires magnetic materials with an order of improvement over existing materials.

Iron-aluminum alloys have been intensively investigated. *Thermenol* and *Alfenol*, developed by the Naval Ordnance Laboratory, are by now well-known materials. Current attention is on rare earth alloys, ferrites, and garnets, and on their preparation and processing methods. The effects of irradiation on the properties of magnetic materials are being fully explored. The materials program is supported by a strong research program on molecular magnetism, i.e., magnetic structure and properties of solids, with emphasis on the interatomic and molecular forces involved.

Semiconductor research in the Navy has emphasized optical properties and photo effects for infrared systems. The properties of intermetallic semiconducting compounds—sulfides, tellurides, arsenides, etc.—have been investigated to obtain a better understanding of the mechanisms responsible for the photo effects and the discovery of new effects. The relation between purity or deliberate impurity doping, defect structure, and photo conductivity has received special attention.

Nuclear propulsion systems

The Navy program on pressurized-water nuclear reactors for submarine and ship propulsion is sufficiently well documented to preclude review in this paper. Many metallurgical and corrosion problems required solution for the successful development of the Nautilus and related nuclear propulsion systems.

In the field of nuclear reactors for aerial vehicles, there is a small effort on the problems of liquid metals as heat transfer media, involving corrosion and mass transport studies and the evaluation of container and piping materials. Compatibility of structural materials with molten lithium and the mechanism of surface damage are being investigated. Much of the research in the high-temperature materials and corrosion programs provides support to the problems in this area.

Basic research

It is manifestly impossible in such a brief summary of the Navy R&D Program to describe adequately the comprehensive metallurgy and ceramics basic research program supported by the Navy through its sponsored contract research activity and its *in-house* laboratory effort. Hundreds of individual research tasks and several millions of dollars are involved annually. The results of Navy-sponsored research—much of which is carried out at universities—are continuously being reported in the scientific literature.

Basic research is considered a most essential component of the overall Navy Materials R&D Program. The program has the dual motivation of research by necessity and research for opportunity. That is, the basic research program not only directly supports the applied research and development phases but, in addition, provides the fountainhead of new ideas, new concepts, and new materials for these more applied programs. Because of our objective in trying to improve the understanding of the relationships between structure—micro, crystallographic, atomic, and imperfection—and properties, we are obviously concerned with all facets of research in physical metallurgy and physics of metals.

Some of the prominent areas of research currently receiving attention are listed in Table I. It is important to note the attention to electron transport properties and behavior, in addition to the studies on flow and fracture and solid-state reactions. From a materials orientation viewpoint, the metallurgy research program has primary emphasis on structure-sensitive properties and reactions, i.e., How does the composition, micro structure, defect concentration, impurity level, thermal-mechanical history, etc., control the various physical and mechanical phenomena which underly the applications of alloys and ceramics? Strong support to the Materials Research programs comes from related research programs in solid-state physics and chemistry.

Conclusion

It is obvious that many difficult materials problems face the Navy as a result of its advancing technology and weapons systems. We are confident that the applied research and development programs now underway or being planned, supported by a strong basic research program, will lead to major improvements and to the introduction of new types of materials required to solve our problems. This is particularly true if we maintain the responsibility and capability of being alert to exploit any scientific or engineering advance in materials and processes, no matter what its origin.

Table I. Basic Research

1. Mechanical Behavior of Solids
2. (Electron) Transport Properties in Solids
3. Imperfections in Solids
4. Crystal Growth and Morphology
5. Nature, Properties and Behavior of Surfaces (including corrosion)
6. Phase Transformations
7. Diffusion and Mass Transport
8. Structure and Properties of Liquids
9. Alloy Theory and Cohesion
10. High Pressure Research
11. Whiskers and Thin Films
12. Optical and Thermal Properties of Solids
13. High Temperature Properties and Reactions
14. Instrumentation and Techniques
15. Radiation Effects
16. Magnetic Properties and Magnetism
17. Strengthening Mechanisms in Solids

2. The Navy's Refractory Metals Program

by T. F. Kearns and J. Maltz

The refractory metals are defined in terms of melting point, as listed in Table I. The cut-off point may be 3000°F or any other convenient and arbitrary figure. This is largely confined to the upper portion of the table. When considerations of price and scarcity are added, attention is focused on tungsten, tantalum, molybdenum, or columbium for any but the most specialized applications. This is not to say that the Navy has no interest in the lower portion of the table, but only that such interest will not be dwelt upon here.

Tungsten and molybdenum are neighbors in Group VI A of the Periodic Table where interatomic bonding is such as to emphasize strength and rigidity at the expense of low-temperature ductility. They have low solubility for interstitial elements and are prone to further embrittlement at low contamination levels. Tantalum and columbium are in the adjacent Group V A. As compared to tungsten and molybdenum, they have greater solubility for interstitials; are somewhat weaker; considerably less stiff; and much less difficult to fabricate. Although all four metals have body-centered-cubic lattices, tungsten normally has ductile-to-brittle bend transition range well above room temperature; molybdenum has one near room temperature; columbium remains ductile, if not grossly contaminated, well below room temperature; and tantalum remains ductile to 200°F or below. As a result of this difference, the four metals appear to have separate but overlapping areas of usefulness, depending on the relative importance of strength and fabricability in the end-item one wishes to construct.

The Navy refractory metal program was started in 1947 when it became clear that the trend toward higher and higher equipment operating temperatures had no apparent limitation other than the capabilities of available materials. It was clear that as temperatures approached and exceeded the melting points of the then-used iron, nickel, and cobalt-base alloys, new materials with higher melting points would be required. The refractory metals provided one promising family of materials which met this requirement.

Mo, the initial emphasis

The Navy placed initial emphasis on the development of molybdenum alloys. This decision was based on cost and availability advantages over columbium, tantalum, rhenium, and the platinum-group metals, and density advantages over tungsten, tantalum, and rhenium. It may be recalled that columbium supplies at that time were much more limited than they are today. It may also be recalled that rotating parts such as turbine blades were then receiving major attention, and that the stresses in such parts, resulting from centrifugal force, increase as a direct function of density.

As a result of more than a decade of steady progress, a large body of results has been assembled for molybdenum alloys. A few high points are listed below:

1) Room-temperature brittleness is related to grain boundary oxide formation. A carbon deoxidation technique resulted in the production of workable material;

2) The size limitations of the then-existing powder metallurgy techniques for producing large ingots were overcome by the development of the vacuum arc casting process. Twelve-in. diam arc-cast ingots, weighing 1800 lb, are now regularly produced and even larger ones will soon be available;

3) The cast ingot breakdown problem was solved —at least on an interim basis—by the application of the glass extrusion process. The term *interim basis* is used because existing breakdown equipment can operate with only a small extrusion ratio and uneconomical recovery rates. More desirable solutions are in sight and are described later;

4) Vacuum technology for controlling interstitial contamination during processing has been developed;

5) Analytical techniques for impurities in the parts-per-million-range have been improved;

6) A number of useful alloys have been developed. The Mo-Ti-Zr-C alloys are strengthened by a mechanism which, though not yet perfectly understood, involves a fine dispersion of carbides and perhaps oxides. In some of the more interesting new alloys, titanium has been increased from 0.5 pct to about 2 pct with proportionate increases in the amount of carbon. The use of solid-solution strengtheners to supplement the dispersion effect has produced alloys with extremely high tensile strength at 2400°F and above.

Inasmuch as none of these alloys responds to hardening by heat treatment, they are used in the hot-cold worked condition. Consequently, a high recrystallization temperature is important. The recrystallization temperatures of molybdenum alloys in the pre-production state are above 2600°F. This is an advancement of some 700°F over that of pure molybdenum; and

7) Dramatic increases in ductility have been achieved by rather large additions of rhenium to

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molybdenum, as illustrated in Table II. The effect is also noted, although not as dramatically, when rhenium is added to tungsten. Recently, research has demonstrated that several effects are involved: oxygen redistribution in the grain boundries, introduction of a twinning mechanism for deformation, and unlocking of dislocations. Although cost and availability make impracticable the use of rhenium in such percentages in alloys of general application, and no plentiful substitute has as yet been found, certain limited applications, such as in weld filler metal, are likely. More important, this work has provided a spur to refractory metal research. There is now evidence that some of the rhenium effects may be conferred by a combination of more plentiful addition elements.

The expanded program

About three years ago the Navy, foreseeing the need for refractory metals in major new applications, expanded and intensified its program. Table III shows the program which was mapped out. Several portions of that program have already been completed; others are in progress. As an example, we may consider the item of high-purity refining. It is only by approaching the ultimate in purity that we can determine whether true ductility is obtainable at/and below room temperature in such metals as tungsten or chromium, or for that matter, in many other metals, such as beryllium.

Raw Materials

In the raw material area, vacuum techniques are being used to produce extremely fine and pure powders of columbium and tantalum (less than 1μ diam) as a possible starting material for dispersion strengthening. Dispersion strengthening of molybdenum is also being attempted by internal oxidation of Mo-Ti and Mo-Cb alloy powders which, having the dispersed oxides already distributed throughout the powder particles, may be compacted, sintered, extruded, and forged or rolled to shape. The phenomenon of oxide dispersion-strengthened molybdenum has, of course, already been reported. The objective here is to achieve the increase in recrystallization temperature and strength, while maintaining good low-temperature ductility.

Alloys

In alloy development, studies of the Mo-Ti-Zr-C series are being continued. Binary alloys of tungsten with a variety of other metals and ternaries of molybdenum-tungsten with various additions are also under study. A series of platinum-base binary alloys is also receiving attention. In tantalum, ternaries with about 10 pct W, sometimes supplemented with hafnium or rhenium, are the areas of concentration, although some alloys of higher tungsten content are being checked.

It may be interesting to note some results achieved in vanadium and chromium alloy development programs. In vanadium, short-time tensile strengths of 50,000 psi at 2000°F for annealed materials have been attained. On a strength:weight basis this compares favorably with the best available sheet materials at this temperature. In chromium, it is of interest to note that yttrium and cerium can be added to the very limited list of additions which lower the ductile-to-brittle transition temperature. The lowest bend transition temperature, 40°F, has been attained with hydrogen-reduced chromium containing 1 pct Y.

Fabrication

In fabrication, a series of studies is in progress ranging from explosive forming and spinning of sheet and other preforms to plasma jet spraying. This work is directed mainly at tungsten and molybdenum alloys, in view of the fabrication difficulties encountered with these materials.

The plasma jet and the electron beam are being employed as possible improved tools for welding. The theory of ultrasonic welding is being refined. Fig. 1 is a photomicrograph of a cross section of a molybdenum alloy weld made ultrasonically. The faying surface has virtually disappeared, even though no melting or gross recrystallization can be observed in the weld area.

Protective Coatings

In the protective coating field, there is still much to be desired. A great deal of the past work on protective coatings for molybdenum, starting with the

Table I. Refractory Metals

	Melting Point, °C	Melting Point, °F	Density, g per cu cm	Young's Modulus, 10^6 psi
Tungsten	3410	6170	19.3	50
Rhenium	3180	5740	20.0	67
Tantalum	2996	5425	16.6	27
Osmium	2700	4900	22.5	80
Molybdenum	2610	4730	10.2	45
Ruthenium	2500	4535	12.2	—
Iridium	2454	4450	22.5	75
Columbium	2415	4379	8.57	15
Rhodium	1966	3570	12.4	41
Chromium	1890	3430	7.19	36
Zirconium	1860	3380	6.5	14
Titanium	1725	3140	4.5	15
Vanadium	1720	3125	6.11	22
Hafnium	1705	3100	11.4	20

Table II. Workability of Cast Mo-Re Alloys

Rhenium, Atomic Pct	Pct Reduction before Cracking		
	Room Temp	500°C	1250°C
0	10	—	10-15
5	—	14	15
15	—	20	22
25	18	>94	32, >95
30	19	>93	>95
35	>95	>94	>94
40	18	>93	>93
50	10	10	10

Table III. Navy Department Refractory Metals Program

A. Compilation of Available Data

B. Establishment of Adequate Source Materials
   1. Availability of material
   2. Methods of extraction, melting, and consolidation
   3. High-purity refining
   4. Determination of purity

C. Alloy Development
   1. Binary and ternary phase diagrams as necessary
   2. Solid-solution alloys
   3. Precipitation-hardening systems
   4. Other high-temperature strengthening techniques

D. Physical Metallurgy
   1. Self-diffusion and inter-diffusion coefficients
   2. Transformation mechanisms and kinetics
   3. Recrystallization behavior
   4. Plasticity and fracture behavior
   5. Metallography and fractography

E. Corrosion, Oxidation, and Surface Protection
   1. Environment resistance
   2. Mechanism and kinetics of oxidation
   3. Surface protection

F. Evaluation of Material
   1. Workability
   2. Fabricability, including welding
   3. Design data, including mechanical physical properties
   4. User and service evaluation

silicide coating formed in place by hydrogen-reduction of $SiCl_4$, has been previously described by others. The silicide coating protected molybdenum against oxidation very successfully for several thousand hours at 2000°F. Its shortcoming was its inability to tolerate any distortion of the basic metal, coupled with its sensitivity to damage. Electroplated coatings, dipped coatings, sprayed coatings, cementation coatings, and even refractories troweled on ¼-in. thick have all been tried and have all achieved success within their limitations. However, as in the case of long-time operation at temperatures over 3000°F or where high thermal shock or abrasive damage is encountered at lower temperatures, there is still room for improvement.

In its current work, the Navy is evaluating several of the more promising molybdenum alloy coatings under conditions of stress, temperature, damage, thermal shock, and oxidation environment characteristic of end-item exposure. It is also studying possible new coating materials, primarily metal-ceramic composites.

In this field, one new development seems rather remarkable. Fig. 2 is a photomicrograph of a coating produced by diffusing zinc onto the surface of columbium. It doesn't seem to make much difference how the zinc is applied—whether by dipping, spraying, vapor deposition, or electroplating. After diffusion, there are formed compounds which vary from $CbZn_5$ on the outside layers beneath the surface oxides, through the very hard lower zinc compounds, to the basis columbium. This coating has protected columbium not only against surface oxidation but also against oxygen pickup, as evidenced by no change in the hardness in 500-800 hr at 1800°F. The coating seems to have excellent throwing power, for example, coating without difficulty the inside of long, thin drilled holes. Perhaps its outstanding characteristic is its ability to withstand damage. [This development was reported by G. Sandoz on p. 340 of the April issue of JOURNAL OF METALS.]

This investigation is still in a very early state. The zinc coating has been tried on the other refractory metals, with some success on tantalum but little success on molybdenum and tungsten. It is limited in its present form to temperatures on the order of 2000°-2200°F.

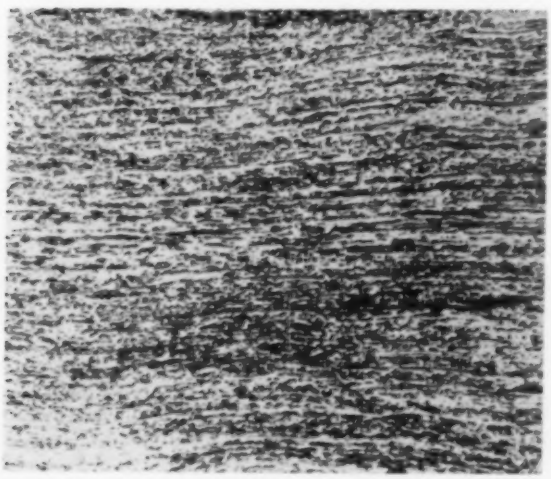

Fig. 1—Cross section of a molybdenum alloy weld made ultrasonically.

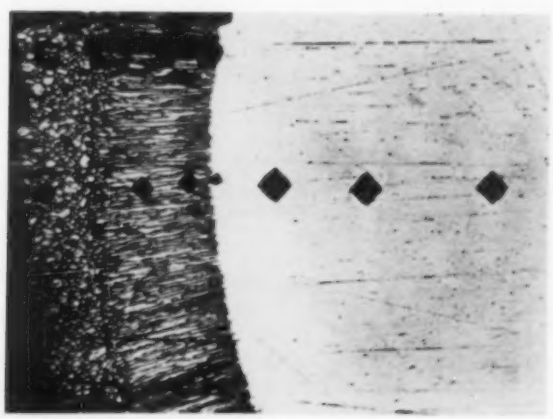

Fig. 2—Coating produced by diffusing zinc onto columbium surface.

Sheet Program

The program just outlined is quite broad and is aimed at studying many phases of refractory metal science. However, one portion of it, in particular, seems to require greater emphasis. It has been estimated that the bulk of the newer requirements for refractory metals will be for material in sheet form, and that the rate of growth of the need is too great to be met by normal commercial development. Accordingly, a major effort in refractory metals development now in progress is aimed at the production of uniform, high-quality sheet. This Refractory Metals Sheet Program is quite analogous to the earlier Titanium Sheet Rolling Program. Briefly, the objective of the sheet program is to put the laboratory advances that have already been achieved to work in the form of a fully-reliable product whose properties are known and can be depended on for design purposes.

In order to develop the kind of information that is needed for control of the production processes, it is necessary to produce a good quantity of material. The program is, therefore, a large one, costing several millions of dollars. Under it, thousands of pounds of refractory metal sheet will be produced. It is a *cradle-to-the-grave* affair starting with the processes for production of the raw material and proceeding through consolidation, melting, ingot production, breakdown, rolling to sheet, measurement of sheet properties, and finally, evaluation of the manufacturing characteristics and actual performance of the material by construction and testing of a few typical end-items, such as ramjet motors or rocket nozzle inserts.

The sheet program itself does not include any significant effort in alloy development. In fact, one of the ground rules for inclusion of alloys in this program is that the laboratory work shall have already been done and that the alloy shall have been produced in quantities large enough to remove any uncertainty regarding the properties of the alloy. This quantity is on the order of 5 to 6-in. diam billets, from which sheets 12 to 18-in. wide by 3 to 4 ft long have been made. This ground rule will probably be waived in the case of tungsten, and some effort may also be applied to other alloys at earlier stages but, in general, alloys farthest along in their development lines will be emphasized.

In a program of this size, the penalty for error is large indeed. In order to minimize this possibility, as well as to insure proper consideration of all factors such as possible production difficulties . . . the actual performance requirements imposed in end-items . . . the kind of manufacturing operations that will be encountered . . . the importance of such characteristics as weldability . . . etc., the Navy, through the Materials Advisory Board of the National Academy of Sciences, has enlisted the services of an advisory panel. The panel is composed of people representing the materials producers, designers, and end-item manufacturers.

One of the first efforts under this program has been to examine, on the one hand, all available data on refractory sheet alloys and, on the other hand, all foreseeable military requirements for such alloys and to formulate a set of realistic target properties which sheet produced under the program should strive to meet. Candidate alloys are now being examined carefully and those most likely to meet the goals will be selected for inclusion in the sheet program.

Table IV is a partial list of candidate alloys. There are, of course, many more alloys being screened, but most of the others do not yet meet pre-production criteria for candidate alloys. Fig. 3 shows the strength divided by density of some of the strongest candidates in the range 2000°-3000°F. More recent data, not shown, are available for considerably higher temperatures. On a strength:weight basis the competition between molybdenum and columbium alloys is close around 2000°F. At higher temperatures, we have in the molybdenum alloy series the highest strength:weight alloys now available. Approaching 3000°F, it seems certain that tungsten or tantalum-tungsten will be unrivaled in this respect.

Several studies are already in progress under the sheet rolling program. The first is the production of higher-quality molybdenum alloy sheet approx 36x96 in. by the best available production techniques involving arc-melted ingot. Mo-0.5 pct Ti and Mo-0.5 pct Ti-0.10 pct Zr have been selected for inclusion in this program.

A second project involves the production of molybdenum alloy sheet by powder metallurgy techniques. Although powder metallurgy has some real advantages over arc melting—fine grain size, for example, —no alloys based upon powder metallurgy have yet been developed which are competitive with the best arc-melted alloys in the higher temperature range. This is attributable to current alloying limitations of the powder metallurgy technique.

In another study, unusual techniques are being examined to produce the finest practicable grade of molybdenum for subsequent consolidation. In particular, the effects of various interstitials on sheet quality are being tied down. Some of the techniques being tried are bomb reduction (to control hydrogen); hydrogen reduction and post-reduction processing (to control oxygen); and electron beam melting (to control carbon).

The practicability of direct extrusion of powder to sheet bar and of direct rolling of powder to sheet as a means of eliminating the costs and possible shortcomings of melting and ingot processing or pressing and sintering is also being investigated.

The most recent program covers the production of high-quality 18x48x0.060 in. tungsten sheet. In this case, because of the lack of suitable tungsten alloy candidates, the first effort will be aimed at unalloyed tungsten.

Supplementing the Bureau of Naval Weapons' Refractory Metal Sheet Rolling Program, the Air Material Command of the Air Force is sponsoring programs on the development of manufacturing methods for large columbium alloy sheet and extrusions.

Table IV. Candidate Refractory Sheet Alloys

Mo Alloys	Cb Alloys	Ta Alloys	W Alloys
0.5Ti	15W-5Mo-1Zr	7.5W (PM)	No Alloys
0.5Ti-0.07Zr	15W-5Mo-5Ti-1Zr	10W (PM)	
0.05Zr	1Zr	10W (EBM)	
0.5Zr	10Ti-10Mo		
1.25Ti-0.15Zr-0.15C	33Ta-0.7Zr		

PM—Powder Metallurgy
EBM—Electron-Beam Melted
All Others Arc-Melted

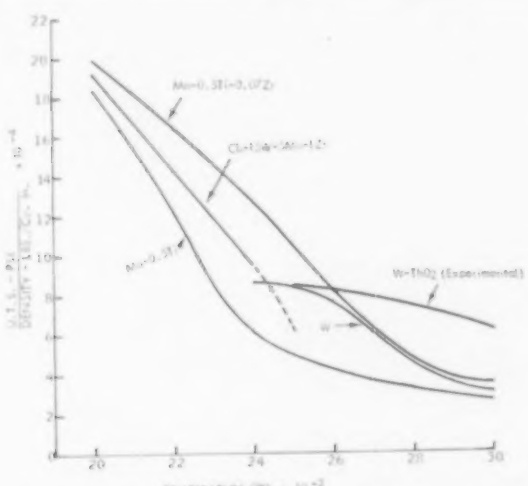

Fig. 3—Ultimate tensile strength:weight ratio for some of the strongest refractory metal alloys in the 2000°-3000°F range.

Infad

A highly novel facility is just being completed and placed in operation for the Bureau of Naval Weapons at Bridgeville, Pa. This is an air-tight room, approx 80x40x25 ft, for processing refractory metals under true hot-working conditions. The room is filled with argon and equipped with a recirculation and purification system capable of maintaining the total impurity level at 50 ppm or less. At present, the principal pieces of equipment [described in some detail in another article in this issue] are a forging impactor and a versatile rolling mill, which, together, are capable of processing ingot to sheet at temperatures up to 4000°F. The facility was sponsored by the Navy specifically to provide this processing capability as an aid to research and development programs, which may be scheduled into the room by arrangement with the Bureau of Naval Weapons.

Conclusions

All in all, we feel that the Navy has a broad, aggressive refractory metals development program which should contribute significantly to the advancement of this important area.

3. Direct Energy Conversion

by Paul H. Egli

Improved power source and energy conversion systems represent one of the most important long-range scientific problems facing the Nation. A rapidly increasing population and an increasing per capita usage of energy, coupled with declining fuel reserves, poses a problem of serious proportions. Space exploration consumes energy at fantastic rates, and the race for space domination will unquestionably be won by the nation which can best provide the energy requirements.

The military services have difficult, immediate problems which require new power systems, and part of the efforts to solve these problems is represented by the research and development program on direct conversion. Navy requirements can be catalogued in three general areas of usage: flight vehicles, both air and space; remote locations, including portable power and unattended sites, such as underwater installations; and shipboard power, both for propulsion and for auxiliary uses.

Each area of usage involves unique requirements. In the case of space vehicles, for example, weight is a prime consideration; consequently, pounds-per-kilowatt is more important than efficiency per se. In unmanned vehicles and remote locations freedom from maintenance is an additional necessity. For shipboard use, silence is an important consideration, in addition to space, weight, and efficiency; again, reliability and low maintenance are important elements in the choice of a power system. For all of these requirements, various kinds of direct conversion processes deserves investigation.

Research on direct conversion is directed primarily toward utilization of nuclear energy. The same conversion processes, however, work equally well with other sources of energy, and for any particular application all possible combinations of energy source and conversion processes should be examined.

Direct conversion, what is it?

Before discussing the conversion processes, it may be helpful to define *direct conversions*. A reasonable statement is that direct conversion includes any process in which energy is not transferred to a secondary working fluid. For example, a combustion engine in which heat expands a vapor that pushes against pistons or a turbine in which gas or steam works against blades is obviously not direct. Magnetohydrodynamics could be challenged because it employs a working fluid. In most systems the expansion and subsequent pressure drop of the plasma are not the heart of the process; hence, for convenience they are normally regarded as direct conversion. Thermionic emission and thermoelectricity are clearly direct conversion. Direct collection of charge from the various particles in nuclear reactions would admittedly be even more direct, but many suggestions for such processes have been carefully examined, and none of them looks even remotely promising.

Four energy conversion processes are receiving the majority of attention: photovoltaic cells, thermoelectricity, thermionic emission, and fuel cells. Other possibilities exist, such as magnetohydrodynamics, which, to become feasible, must wait for the solution of extremely difficult high-temperature materials problems. Pyroelectricity, Curie-point inversions, and several others could be mentioned, but they all appear to have serious limitations except for special applications. Those which look immediately promising are the first four listed.

Solar cells

The most highly developed energy conversion processes today are the solar cells, which utilize energy in the form of radiation. The most familiar form is a very perfect silicon crystal which is treated with traces of impurities that introduce extra positive and negative charges on the two sides of a thin wafer (Fig. 1). These extra charges remain on their respective sides of the junction until light energy strikes the crystal. This radiant energy further disturbs the electrical balance of charges and starts them moving toward the surfaces and the junction. The current flow continues as long as light strikes the crystal.

The physics of this process is reasonably well understood. Theory tells us that as much as 25 pct of the incident radiation can be converted to electricity, and under special conditions possibly as much as 40 pct. The best now reported from the laboratory is 14 pct, and substantial production quantities can be obtained that give a 10 pct conversion efficiency. The cells are reliable and operate indefinitely with no loss in efficiency.

These processes represent the best available means of providing small amounts of power for satellite communications. The cells last so long that a time switch must be incorporated to shut off transmission after the desired interval; they are limited to small power supplies, however, because of their weight. Bare cells produce only 3 w per lb. In a satellite, they must be distributed over the surface of a free tumbling sphere, or a mechanism must be provided to keep them pointed at the sun. A third possibility is to use the solar cells to charge batteries, which in turn provide current during dark periods—but all of these schemes add weight. Thus, the power supply might weigh more than 1000 lb per kw, which is far too heavy to boost into space.

As large power supplies for ground stations, solar cells have the dual problem of size and cost. For example, a 10-kw generator suitable for a modern

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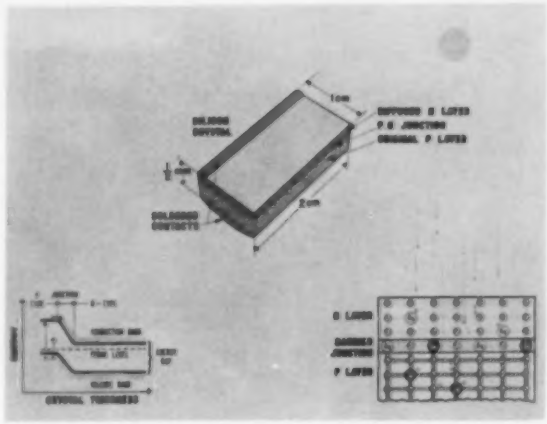
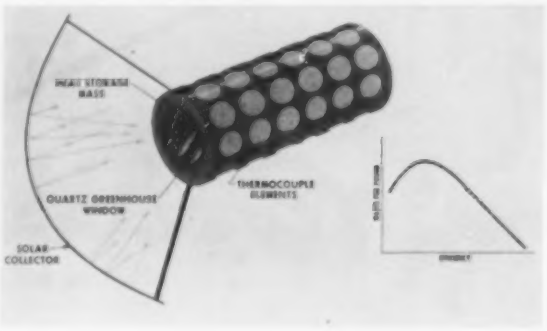
home power supply would occupy 100 sq yd and cost $2 million.

As with all direct conversion processes, the problem is primarily one of improved materials. Most of the research effort is directed toward improved efficiency by growing more perfect crystals and by experimenting with different materials, such as gallium arsenide and cadmium sulfide. Some increased efficiency can be expected, but probably by no more than a factor of two. For space applications, it would appear more profitable to attack the weight problem directly, because the active region of the crystal is only a few millionths of an inch thick—a tiny fraction of the total thickness of the present wafers. There appears to be much room for improvement by using crystals in the form of thin films, and substantial improvements must be made for solar cells to remain competitive as other devices are developed. The best projection using existing solar cell techniques predicts 120 lb per kw, which is still much too heavy.





UTILIZATION OF SOLAR ENERGY: Fig. 1—Above, solar cell of a perfect silicon crystal. Fig. 2—Below, solar thermal power supply.

Thermoelectricity

Another method for the utilization of solar energy is collecting it and absorbing the heat content. For example, a mirror could be employed to collect and focus the sun's energy into a metal cylinder, where the concentrated heat could be used to operate thermocouples or thermionic diodes (Fig. 2). In this case, heat would flow from the hot interior of the cylinder through the energy conversion device, creating electricity; the waste heat would be radiated into space, or in case of a ground installation, would be discharged into a body of water.

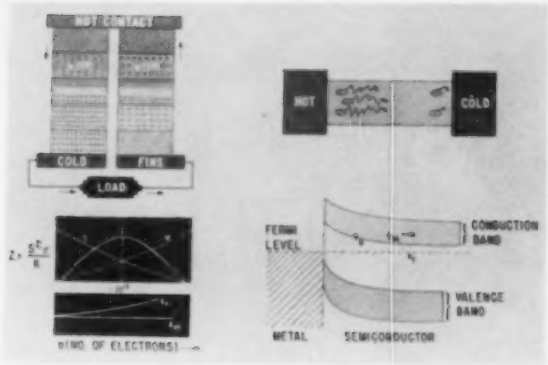
The heat conversion process receiving most attention at present is thermoelectricity. This is basically a very simple phenomenon (Fig. 3). If a temperature difference is maintained across any bar of a material which conducts electricity, the electrons at the hot end of the bar move about more vigorously and tend to drift toward the cold end. It is entirely proper to say that heat pushes electricity through the bar. In some materials it is negative charges that move and in other materials the positive charges move. These opposite effects can be added together when the two types of materials are properly selected and joined so as to form a thermocouple.

Thermoelectricity has a long history. It was discovered in 1822, and efficiencies as high as 3 pct could be obtained in 1850. This was a higher efficiency than was obtained by the steam engines of that day. The scientists involved took a wrong turn, however, and no further progress was made, except that thermocouples have been widely used to measure temperature. Research in physics has recently taught us that to produce substantial amounts of power by the thermoelectric process, metals—which were the materials always used in thermocouples—are the wrong materials. Metals have so many free electrons that increasing the temperature simply causes them to become more crowded, with little chance to drift. It is now recognized that semiconductors such as lead telluride which have much smaller numbers of free electrons but more freedom to drift can produce substantially larger voltages and currents.

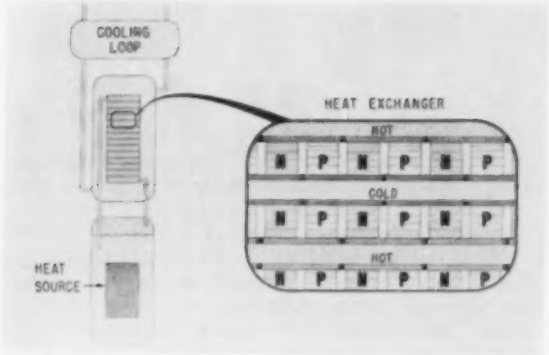
The physics of thermoelectricity is now reasonably well understood. Theory indicates that efficiencies as high as 35 to 50 pct might be achieved. To accomplish this, the materials must have precisely the optimum set of properties in the face of a number of conflicting requirements. As previously stated, the number of free electrons must be small in order to generate a large voltage. But the number of electrons must be large enough to avoid losses from internal resistance, which generates heat that flows in the wrong direction. And, finally, the material must have a low thermal conductivity so that heat cannot flow through the material without doing some electrical work. The optimum compromise that must be reached is shown in the lower left of Fig. 3.

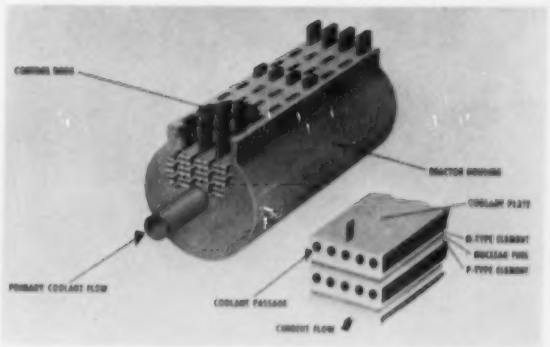
Fairly sophisticated guide lines have been developed for these materials requirements. By following trends that have been established relating the periodic behavior of elements and compounds, together with symmetry considerations to established transport properties, preferred families of chemicals can be selected for investigation. As indicated in Fig. 3, the optimum properties occur with 10^{18} free electrons per cu cm, which means a material very nearly, but not quite, metallic. The requirement is, thus, a semiconductor not quite degenerate, and with a band gap sufficiently broad so that intrinsic carriers are avoided at the operating temperature. Ambipolar complications also are thus avoided. The additional requirement of a low thermal conductivity is less well understood, but it is related to anharmonicity in the lattice, such as occurs in defect structures and in crystals with a large difference in the atomic weight of adjacent atoms.

To complicate the situation further, each of these material properties changes with temperature so that for any given material the best compromise of properties will exist for only a small temperature



THERMOELECTRICITY:
Fig. 3—Left, the thermoelectric effect. Fig. 4—Below and left, a thermoelectric power source. Fig. 5—Below and right, in-pile thermoelectric generator.





range. A thermocouple is a simple heat pump and like all other heat engines, the efficiency increases with larger temperature differences. For one to operate over a wide temperature range, however, requires a number of materials—each efficient in its small temperature region. These several materials can be put in series, as shown at the upper left of Fig. 3, and perform much like the stages of a turbine. This requirement for using several different materials in the same thermocouple, including some that operate at high temperatures, makes the development difficult and expensive. Nevertheless, progress is excellent. The program is now barely started, and a conversion efficiency of 10 pct can be readily obtained. However, half the total heat goes up the chimney when using a fuel burner as the source of heat, so the overall efficiency of the system is reduced to 5 pct. The present weight is about 65 lb per kw, and a design for a space power supply indicates the possibility of 5 lb per kw.

Using thermocouples with nuclear heat is a promising possibility. By surrounding an isotope capsule with thermocouples, nearly all the heat generated can be captured to yield an electrical output of 10 pct or more with today's materials. The present design concept for using thermocouples with reactors involves circulating the primary coolant through a heat exchanger containing the thermoelectric materials, as shown in Fig. 4. No experience is available on which to base a predicted efficiency, but it is reasonable to expect that the heat losses would be substantially smaller, and the efficiency, therefore, higher than with a fuel-fired thermoelectric system.

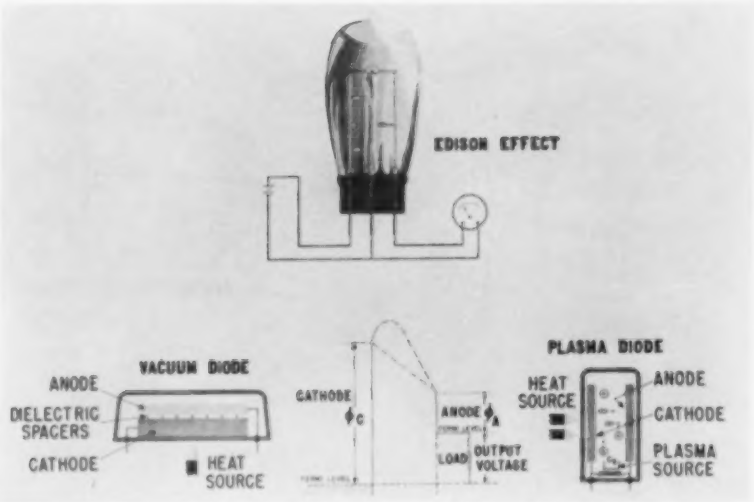
In present designs, the thermocouples are placed in the cooling loop to protect the materials from radiation damage. Ultimately, the thermoelectric elements will be used in the pile as sandwiches immediately adjacent to the fuel, as shown in Fig. 5. There are, in fact, possible fuel materials such as uranium and thorium sulfides, which are themselves semiconductors and, therefore, potential thermoelectric elements. There must be a great deal more study of radiation damage, however, before such a system can be seriously proposed. Although very early results are encouraging, they are by no means sufficient to indicate any kind of conclusion.

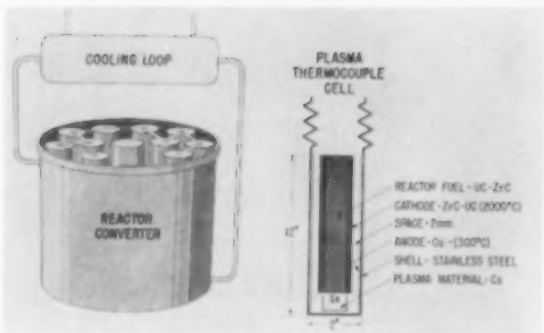
Thermionic emission

The process which does lend itself readily to incorporation in the pile is thermionic emission. This, too, is basically a simple process, and it is based on a discovery by Thomas Edison (Fig. 6). At one period early in his manufacturing of light bulbs, Mr. Edison had two independent filaments in the bulb, only one of which was connected at a time. After the first filament burned out, the bulb was turned around in the socket so that the spare filament was connected. In testing these bulbs Edison discovered that he could draw a small current from the filament that was not connected. Some electricity was moving through the vacuum in the bulb from the hot filament to the cold. This is the basis on which all radio tubes operate, and the same process now promises to become an efficient energy converter.

To generate substantial amounts of power by the thermionic process, it is necessary for large numbers of electrons to flow from the hot cathode to the cold anode. Because the electrons are all negatively

THERMIONIC EMISSION:
Fig. 6—Right, fundamentals of thermionic emission. Fig. 7—Below, a nuclear thermionic converter.





charged, they repel each other and build up a charge that limits further flow. This problem can be minimized by putting the cathode and anode very close together, as shown at the bottom, left, of Fig. 6. The spacing required, however, is less than 0.0001 in., a spacing virtually impossible to keep uniform between two surfaces over a large area, particularly at high temperatures.

Another way to minimize the space charge is to introduce an ionized gas, as shown at the bottom, right, of Fig. 6. Positive charges on the gas plasma neutralize the negative electron charges and permit the current to flow. Calculations indicate that the process could have a theoretical efficiency of 40 pct or more. Efficiencies of up to 13 pct have been demonstrated for brief periods in the laboratory, but enormous difficulties appear in producing a useful, long-lived device. The best available today is a small close-spaced diode with an efficiency of 2 pct.

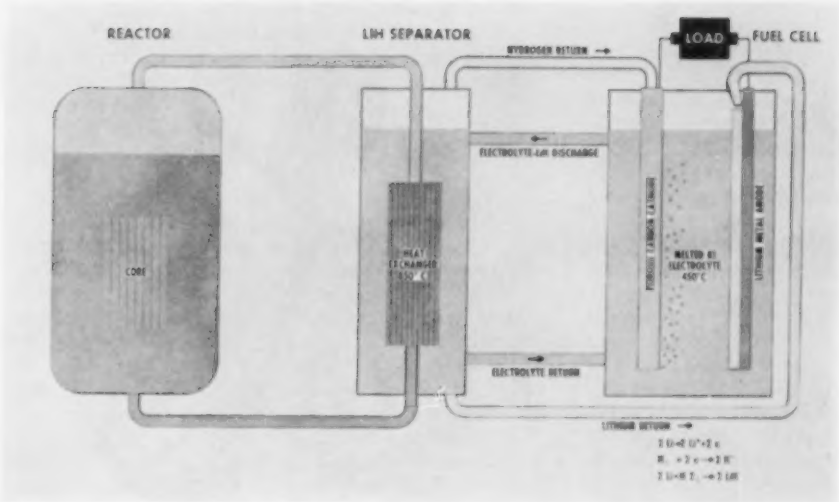
The materials problems are particularly difficult in this case because of the high cathode temperature, together with the corrosive nature of the cesium gas that is the most easily ionized plasma. Tungsten and tantalum metals have received the most attention, but a substantial number of carbides, nitrides, and other refractory compounds are under investigation. Even when the development of long-lived cathodes has been accomplished, serious materials problems will remain in connection with structural parts, particularly seals which are resistant to the cesium corrosion. The behavior of the plasma itself also presents some formidable problems, but the potential advantages of thermionic emitters justifies an aggressive effort to overcome difficulties.

The diode is potentially the lightest in weight of all energy converters. Design projections indicate less than 1 lb per kw—which would make them the obvious choice for space vehicles. The biggest advantage, however, is the simplicity of the in-pile converter. The fuel rod itself acts as the cathode; the can acts as the anode (Fig. 7); very little else is involved. When efficiency and long-lived reliability are achieved, this will certainly be the most simple of the nuclear energy converters.

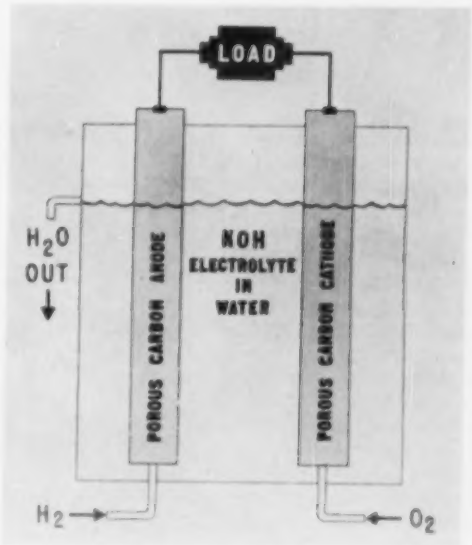
Fuel cells

For high efficiency, however, the continuous-feed cell is the most promising device. Unlike the thermocouple and the diode, the simple fuel cell is not a heat engine. It is a battery and is limited only by chemical reaction principles, in which two chemicals are fed into a cell where they react and produce an electric charge and a chemical byproduct. Theroretically, the fuel cell can approach 100 pct efficiency, and as much as 90 pct has been demonstrated under special laboratory conditions. In the most simple form (Fig. 8), hydrogen and oxygen gas are continuously fed through porous carbon rods, reacting in an electrolyte to form electricity and water. Such cells have operated continuously for five years at low output levels, but they develop problems as output levels are increased. The space required to store hydrogen limits the value of these cells for shipboard and space vehicle uses, but many other applications look promising.

There exist dozens of variations of fuel cells utilizing a variety of chemicals. The most exciting possibility is a fuel cell that would use conventional petroleum products and air as the fuels; several companies have such cells in early stages of development. The general scheme is to use catalysts in the electrodes which would separate hydrogen from the hydrocarbons, and to use oxygen from the air as the other fuel. Such cells have been demonstrated with efficiencies of more than 35 pct at low temperatures and up to 75 pct at higher temperatures. The problem is to keep them operating at high output



FUEL CELLS:
Fig. 8—Below, the Hydrox fuel cell. Fig. 9—Left, the hydride fuel cell, operating in closed thermal cycle.



levels for long periods without having impurities poison the catalysts, thus reducing the efficiency. The weight is not especially good on a lb per kw basis (perhaps 80 lb per kw), but weight per kw-hr of the cell plus its fuel is about twice as good as a conventional power plant plus its fuel, because the higher efficiency cell uses less fuel.

Success in these devices could obviously have large impact on the whole problem of power supplies. An efficiency of 60 pct to 80 pct is a very reasonable goal, and this could result in doubling or tripling the life of our fossil fuel reserves.

Again, however, there are formidable materials problems. A high temperature hydrox cell has failed through years of development to realize its potential, primarily because of difficulties with sintered nickel electrodes. Containment materials for high-temperature acid reaction media are a limitation in the hydrocarbon cells. Even the porous carbon electrodes for low-temperature hydrox cells are far from perfect, but again a substantial materials development effort is justified by the promise of the device.

Fuel cells can also be operated as closed cycles activated by nuclear heat. The chemicals formed by the battery action could be decomposed by heat to reform the original chemicals used in the fuel cell and recirculated indefinitely (Fig. 9). This is a heat engine again, however, limited to less than 35 pct efficiency, and the advantages over the more simple heat engines are not obvious.

Conclusions

The total impact of direct conversion remains to be determined by future developments. No one direct conversion process is expected to be a panacea for all power problems. Each will find applications based on its peculiar virtues. The first uses will be in applications in which silence is more important than efficiency and in remote locations where freedom from maintenance is the determining factor. These applications will be followed by small power sources for various purposes, increasing in size and scope of application as efficiency increases. To say how far this might go would be indulging in predictions from a clouded crystal ball. It is conceivable, for example, that there will be a period in our future when central power stations will give way to individual fuel cells in every home. At a later period when fossil fuels have become so scarce that we can no longer afford to use them for fuels, we may revert to more central distribution— possibly to a nuclear thermoelectric plant in each small neighborhood or country village. Or possibly direct conversion units will be used as topping units or waste heat scrubbers to improve the efficiency of very large nuclear turbine systems.

Direct conversion could, thus, play a dominant role in the total energy picture, and the research and development program deserves a substantial effort. Whether all of the goals can be achieved depends on future developments, particularly in materials. It seems reasonably certain that, with sufficient effort, direct conversion processes will solve important military problems. And it seems reasonable to expect that the progress made in connection with these developments and applications will lead to increasing civilian uses.

4.

Semiconductor Research in the Navy

by W. W. Scanlon

Semiconductor research in naval laboratories is motivated principally by the Navy's interest in using infrared radiation for detecting, ranging, and observation of objects, and communicating with and guiding military devices. Semiconductors possess a number of characteristics which enable them to perform remarkably well in many of these applications. Certain semiconductors are the most sensitive infrared detectors known. Others make windows and lenses which are superior to any other infrared optical material. The sharp optical absorption edge of semiconductors makes them admirably suited as filters for excluding undesirable radiation. In addition, the influence of infrared radiation on the electrical and magnetic properties of semiconductors has proved to be an extremely valuable means of investigating the basic physics of semiconductors.

The maximum utilization of semiconductors in the Navy's infrared applications is dependent upon a thorough knowledge of the basic physics and chemistry of these materials. While much is known of the electrical properties of certain elementary semiconductors such as germanium and silicon, knowledge of the optical properties of these materials has been of somewhat less interest. Furthermore, many of the semiconductors known to be the most sensitive infrared detectors, such as PbS, PbSe, and PbTe, have been almost completely ignored by the transistor people. Thus, research in Navy laboratories has been directed toward increasing our knowledge of the optical properties of the elementary semiconductors and both the electrical and optical properties of certain classes of compound semiconductors which possess useful infrared characteristics.

Three programs, three labs

The research is being conducted principally at three locations; the Naval Research Laboratory, Washington, D. C.; the Naval Ordnance Laboratory, White Oak, Md.; and the Naval Ordnance Laboratory, Corona, Calif. The three programs are basically different, since the respective activities are oriented by the different interests of the groups and the available special research equipment.

The Naval Ordnance Laboratory (NOL), White Oak, is interested principally in those semiconductor materials which have energy gaps on the order of a few tenths of a volt. These semiconductors have optical absorption edges and photoconductivity within wave lengths of approx 1 to 10 μ. Such materials are called intrinsic photoconductors. Typical examples of small energy gap semiconductors are PbS, PbSe, PbTe, and InAs.

The Naval Research Laboratory (NRL) is interested in larger energy gap semiconductors such as germanium and silicon, which have impurity levels within a few hundredths or a few tenths of a volt of conduction bands. These materials, when cooled to liquid nitrogen or helium temperatures, are photoconductive for radiation of wave lengths from approx 10 to 150 μ; they are called impurity photoconductors.

The Naval Ordnance Laboratory, Corona, has been the central testing laboratory for infrared cells made at various places in this Country and abroad. They have provided valuable comparative information on photoconductive cell performance.

Basic research

Much of the research at the Navy laboratories is of a basic nature related to understanding the photoconductive mechanism and related optical properties of semiconductors. For example, the work at the NRL on the far infrared absorption in germanium and silicon—beyond the main band absorption edge where impurity absorption occurs—has contributed much to the understanding of impurity energy levels in semiconductors. These investigations extended to wave lengths of about 40 μ originally, but recently they have instrumentation increasing the limit to about 150 μ. One of the practical results of this work is the zinc-doped germanium infrared cell which responds to radiation out to about 40 μ when cooled

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to 4°K. Current investigations at the NRL are directed toward an understanding of the nature of band edges in semiconductors based on infrared cyclotron resonance studies and magneto-optical absorption measurements.

White Oak's research

At the Naval Ordnance Laboratory, White Oak, research on small band gap semiconductors like PbS, PbSe, and PbTe encountered a materials problem not found in similar investigations on elementary semiconductors. Many of the small band gap semiconductors are compounds, some of which have a substantial polar character in the interatomic bands. Crystals of such materials may exist over a small range of composition near the stoichiometric proportions by the incorporation of lattice vacancies in either sub-lattice or interstitial atoms. These imperfections produce donor or acceptor levels in the semiconductor, in addition to those produced by impurity atoms. The concentration and kind of these imperfections is a complicated function of the temperature and composition of the gaseous and liquid phases surrounding the crystal. A materials problem involving phase relationships had to be solved before reliable investigations of the Hall effect, electrical conductivity, and similar properties could be made. The NOL, White Oak, has made a number of experimental and theoretical contributions to this physical-chemical problem of the phase relations in compound semiconductors and has helped in defining the phase diagram in PbS and PbTe. The information so gained made it possible to prepare a group of crystals of PbS and PbTe having desired range of electrical properties.

Measurements of Hall effect and electrical conductivity in these crystals clarified the problem of the energy gap in these materials and definitely established that they are intrinsic photoconductors. Other basic characteristics of the semiconductors were determined, such as the mobility of electrons and holes . . . scattering processes . . . carrier lifetimes . . . optical absorption properties . . . and effective masses.

The radiative recombination time for electrons and holes in crystal was found to be much too short to account for the observed photoconductive lifetime in films of these materials. Hence, we proposed that a trapping process is important in photoconductive films for extending the carrier lifetime. We pursued this subject further in PbS and PbSe films and established that oxygen produces the trapping levels in films. Using the techniques of field effect studies, we were able to estimate the trap depths, concentrations, and cross sections.

Hall effect and resistivity studies on crystals and films clarified the problem of the photoconductive mechanism. The photoconductivity in lead salts was, thus, determined to be basically a change in the carrier density induced by photon absorption, rather than this effect plus a barrier modulation effect induced by the radiative.

Further information on these materials was obtained from the electrical noise characteristics. We developed a theory for the noise spectrum which clearly indicates the direction for developing more sensitive cells. In addition, this theory permits evaluation of a variety of basic characteristics of the semiconductor, as well as predicting the noise behavior of other semiconductor devices such as diodes and transistors.

We are currently conducting fundamental studies of the energy band structure in these compounds through magneto-resistance and piezo-resistance studies.

Our optical absorption edge data indicates very nearly the same energies for direct and indirect transitions. This, coupled with the magneto-resistance data, suggests—at least for PbTe—that energy surfaces are ellipsoids oriented along the [111] axis and that the extrema of the conductor and valence bands are near the same values of the momentum vector. Our data are not sufficiently precise to comment on the corresponding factor for PbS and PbSe.

A recent advance in the materials preparation work at the NOL, White Oak, is the development of a technique for pulling single crystals of a volatile compound such as PbTe from the melt. These crystals have a more perfect structure than those obtained by the Bridgman technique and will make possible more precise studies of the properties of these semiconductors.

Current investigations include studies of the thermoelectric power of PbTe crystals grown by the pulling technique. This work will shed more light on the effective masses and electron-phonon interactions at low temperatures. Evidence of phonon drag effects upon the thermoelectric power has been found in the purest PbTe crystal at liquid nitrogen temperature.

We have also studied the chemical kinetics of the process for depositing photoconductive films of PbS from solutions. This work has an important bearing on the commercial process used for this purpose.

The program on InAs resembles the lead salt work in that the materials problem had to be worked out first. A similarly comprehensive study of the fundamental physics of this material is being made. We have established some of the features of the energy band edges in InAs and are currently studying the lifetimes, optical absorption, mobility, etc., of single crystals. One of the practical uses of this information was the development of an interference filter for an infrared device now in production.

NOL, Corona

The research program at the NOL, Corona, is relatively new and is related to the problem of interference filters for use in the infrared. Problems of producing films having the same dielectric constant properties of bulk materials are being studied. The major work at this laboratory is on the level of a testing and evaluation of photoconductive cells.

Summary

The effective combination of the disciplines of physics, chemistry, and metallurgy have helped us in the White Oak, NOL, clarify many of the problems that existed in the lead salt semiconductors. The combination also advanced our understanding of how to deal with non-stoichiometric semiconducting compounds.

Through the efforts of these three Navy laboratories, the US Defense Department is being kept abreast on materials which are useful in infrared applications. Some of this work has already resulted in devices useful in the Navy's mission.

5.

Irradiation Effects in Magnetic Materials

by E. I. Salkovitz

Extensive investigations of the effects of nuclear environments upon magnetic materials have been undertaken. The nuclear environment to which we refer includes electromagnetic radiation (i.e., X-rays, gamma rays), fission fragments, and fast and slow neutrons. In non-metallic materials, such as dielectrics, electromagnetic radiation will produce ionization effects. But in metals and alloys which are already ionized, these effects are not expected. Impinging particles, such as fast neutrons may, on the other hand, have sufficient energy to produce atomic displacements in metals and alloys. Consequently, those properties strongly dependent on atomic arrangements will be affected by neutron irradiation.

From the Navy's point of view, radiation environments may be provided by various sources. For example, shipboard and land-based reactors are a possibility. Here, however, it may be possible to design for adequate shielding to prevent serious deleterious effects. In the case of airborne power plants, however, shielding is accomplished only at an extreme cost in weight and space; consequently, electronic and magnetic devices may be expected to encounter nuclear environments. It is also necessary to consider nuclear environments created by nuclear explosions where very intense pulses of radiation are expected. Radar blackout is already a well established consequence of certain types of nuclear explosions. Although the cosmic particles, X-rays, etc., of outer space are not expected to produce atomic displacements, and therefore alter structure-sensitive properties, space cannot be dismissed entirely from consideration, for nuclear-propelled vehicles are planned for distant outer space journeys. These nuclear-powered devices would carry their own reactors and thus produce radiation environments which could bathe various components with nuclear particles. Furthermore, electronic devices used in guidance, control, etc., in various missiles, may be thrown out of commission by certain types of nuclear bursts.

At this point, it is possible to list the types of electronic equipment and components susceptible to radiation and to indicate the amount of information available. In the case of ordinary circuit elements in which resistors, capacitors, and general hardware are lumped together, much data has been accumulated and is in the literature. This is also true for semiconductor devices—diodes, transistors, etc. Transducers and magnetic devices are two categories of components of extreme interest to the Navy. But very little data exists on irradiation effects in transducers, while intensive work on magnetic materials has been conducted only within the last two years, and largely by the Navy[1].

Fig. 1 shows radiation sensitivity of various classes of materials rather than of specific items of hardware. It indicates the total dose of fast or high-energy neutrons which specific classes of materials may tolerate before significant damage occurs, i.e., before, say, a 10 pct alteration occurs in an important property of the material in question. The ordinate scale refers to the total dosage or total number of neutrons striking per sq cm of material. The sensitivity value for magnetic materials is slightly above that at which organic liquids, such as transformer oils, deteriorate but below the dosage which produces structural changes in metals and alloys. The number (10^{17} nvt) corresponds to an exposure for a fraction of a second to a nuclear explosion of present size, or to an exposure for a week or two to direct beams from conventional reactors.

The magnetic hysteresis loop is very useful in studies of changes in magnetic properties due to irradiation because it shows the relationship between the externally-applied magnetic field and the magnetization induced in the sample. Given a material which was magnetically saturated, removal of the applied field results in a residual magnetism, B_r. To reduce this induced magnetization to zero, a field must be applied in the negative direction. The value of the applied field which gives a zero induction is called the coercive force, H_c. The shape of the hysteresis loop and these two parameters are strongly dependent on the atomic arrangement of many of the alloys to be discussed. Specific applications of magnetic devices depend upon the shape of the hysteresis loop of the magnetic materials used. For example, consider the rectangular loop necessary for satisfactory operation of memory storage devices in computers. Various components in the computer operate on the assumption that the storage device has a rectangular loop with relatively sharp corners. If the hysteresis loops were altered, these devices would malfunction.

Experimental results

The irradiation and measurement procedures used in the experiments described here are similar to those previously described[1]. Suffice to say that 60-cycle loops were obtained on toroid samples of various magnetic alloys before and after irradiation.

E. I. SALKOVITZ, formerly with the US Naval Research Laboratory, is now with Metallurgy Branch, ONR, Washington, D. C. This paper was presented at the 1960 AIME Annual Meeting.

SENSITIVITY OF MATERIALS TO PILE RADIATION

NEUTRONS / CM²

- 10^{21} **METALS**
- 10^{20} – 10^{19} CHANGES IN STRUCTURAL PROPERTIES
- 10^{19} – 10^{18} CHANGES IN MAGNETIC AND ELECTRICAL PROPERTIES
- 10^{18} – 10^{17} ORGANIC LIQUIDS DETERIORATE
- 10^{16} RUBBER LOSES ELASTICITY
- 10^{15} PLASTICS DETERIORATE
  GLASS COLORS
- 10^{14} SEMICONDUCTORS MALFUNCTION

Fig. 1

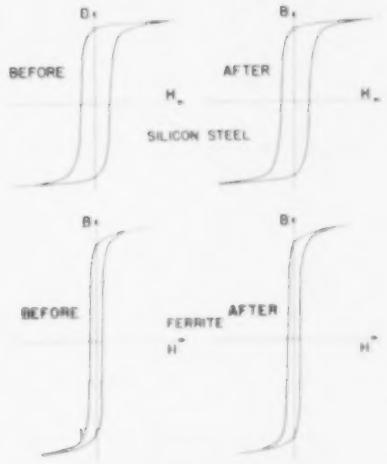
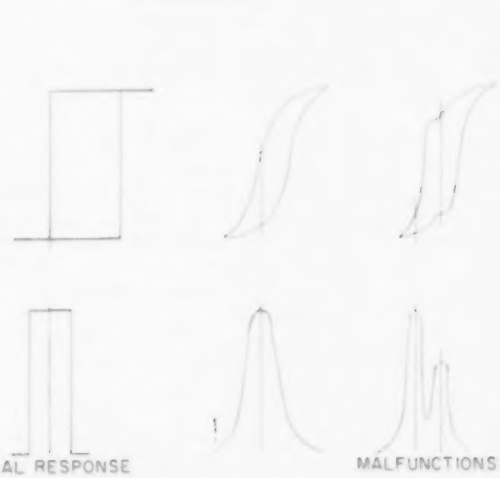


Fig. 2—Radiation insensitive alloys.

Fig. 3 (above) & Fig. 4 (below)—Grossly sensitive alloys.



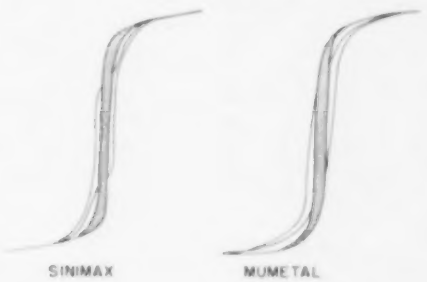
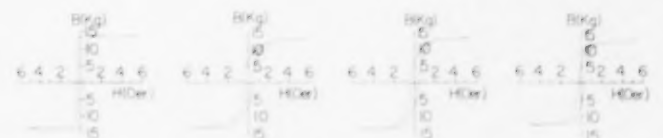
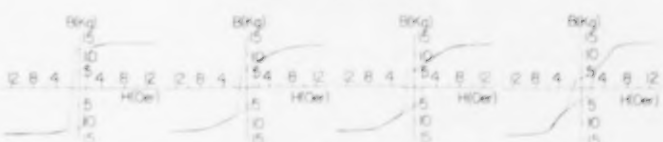


Fig. 5—Above, hysteresis loops and corresponding feed-out pulses.



BEFORE IRRADIATION



AFTER IRRADIATION

Fig. 6—Right, hysteresis loops before and after irradiation.

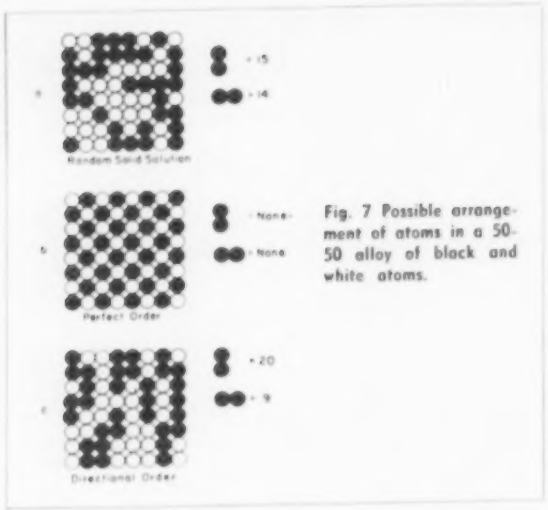


Fig. 7 Possible arrangement of atoms in a 50-50 alloy of black and white atoms.

All measurements were made in the Naval Research Laboratory hot cell using the same circuitry. The samples were irradiated in the Brookhaven graphite reactor operating between 15 and 22 Mw during the various exposures. The total integrated flux received by the samples varied between 6×10^{16} and 3×10^{17} nvt. By means of forced cooling, the temperatures of all samples were kept below 75°C and some as low as 30°C.

As indicated in reference 1, certain materials were found to be insensitive to radiation with respect to their 60-cycle characteristics; therefore, would not require shielding. These materials included silicon steel and similar alloys (Fig. 2) and many types of commercial ferrites (mixed iron oxides). These alloys are also relatively stable to mechanical and thermal treatment. Unfortunately, they do not have very exciting magnetic properties and are not used in sophisticated electronic and magnetic devices.

On the other hand, it was also shown that a large class of alloys are grossly affected (Figs. 3 and 4). In some cases not only are the remanence and coercive force altered, but constrictions are introduced in the hysteresis loop itself. The practical significance of these changes may be inferred from Fig. 5. In its upper left corner is an ideal hysteresis loop for a memory storage device which might be used in an airborne computer, for example; the hysteresis loop is rectangular with sharp corners. The feed-out pulse from a device with such a loop would, in turn, be rectangular with sharp corners, as shown below (or to be more exact, the pulse would have the shape of a delta function). The more conventional loop is shown in the middle with the corresponding bell-shaped feed-out pulse. But if a constriction is introduced into the hysteresis loop, as in the upper right hand corner, the feed-out pulse has two peaks, and certainly a device whose operation is predicated on receiving only sharp single-peaked responses would grossly malfunction.

Highly sensitive alloys

It may be stated categorically that those alloys whose magnetic properties show significant sensitivity to nuclear irradiation are the materials which originally have been given enhanced magnetic properties through special combined mechanical and thermal treatment, i.e., the permalloy treatment. A detailed understanding of the mechanisms involved in the permalloy treatment is not available; however, the treatment arranges the nickel and iron atoms into a nearly regular arrangement or order. Consequently, atomic displacements produced by impinging neutrons can cause the degree of order to be altered considerably, and those magnetic properties sensitive to atomic arrangement are altered. Within recent years, Kaya[2] and others have shown a correlation between the shape of the hysteresis loop and the degree of order in permalloys. Schindler, Salkovitz, and Ansell[3] have given a variety of heat treatments to various types of 50-50 and 75-25 nickel-iron alloys in the form of tape wound toroids. These treatments brought each sample to some particular state of order and characteristic hysteresis loops. Each sample was then irradiated, and the new loops recorded. The nature of resulting changes in the loops (Fig. 6) were found to be dependent on the nature of the loop of the pre-irradiated sample and, therefore, the degree of order in the original sample. The constricted loop in the lower right corner is characteristic of partially-ordered material. A material which orders more readily is supermalloy (75 Ni-25 Fe). Schindler, Salkovitz, and Ansell were able to show that with irradiation a higher degree of order could be obtained than with a given thermal treatment. The results of this paper confirmed work by others[4], that the degree of order may be altered not only thermally but also by irradiation and that the two processes are additive.

Magnetic annealing theories

Several theories which have been developed in the last few years explain magnetic annealing in alloys. Consider an unordered solid solution of atoms A and B, as in Fig. 7a, where the solid circles represent A atoms and the open circles represent B atoms. For ideal random arrangement, 28 pairs of each type of atom are expected, and 56 mixed. In fact, there are 29AA, 29BB, and 54AB pairs. For perfect order no like-atom pairs are expected, as in Fig. 7b. But, there is a third example to consider, as shown in Fig. 7c. Here, there are 29 pairs of AA, but 20 are in the vertical direction, and 9 are horizontal. This is not order in the usual crystallographic sense, yet it shows a definite directionality as a result of preferential alignment of like-atom pairs. On such a model Néel and Taniguchi[5] independently proposed an explanation for the uniaxial magnetic anisotropy that occurs in binary alloys annealed in a magnetic field.

If the normal magnetic anisotropy is small, as in the case of permalloys, then any additional uniaxial anisotropy has a strong effect on the magnetization process. The direction of the uniaxial anisotropy that is created by annealing in a magnetic field is the same for all of the magnetic domains, and this results in a square hysteresis loop. Annealing in the absence of a magnetic field also causes uniaxial anisotropy, but the direction of the anisotropy will be different from domain to domain, and a constricted or kinked hysteresis loop will be obtained. An indirect method for examining the growth of uniaxial anisotropy, then, consists of studying the magnetic hysteresis loop. For iron-nickel alloys, there is also a tendency for long-range superlattice formation, i.e., formation of Ni_3Fe. As the Ni_3Fe superlattice forms, short-range directional ordering occurs, consequently, uniaxial anisotropy decreases. As a result, a normal

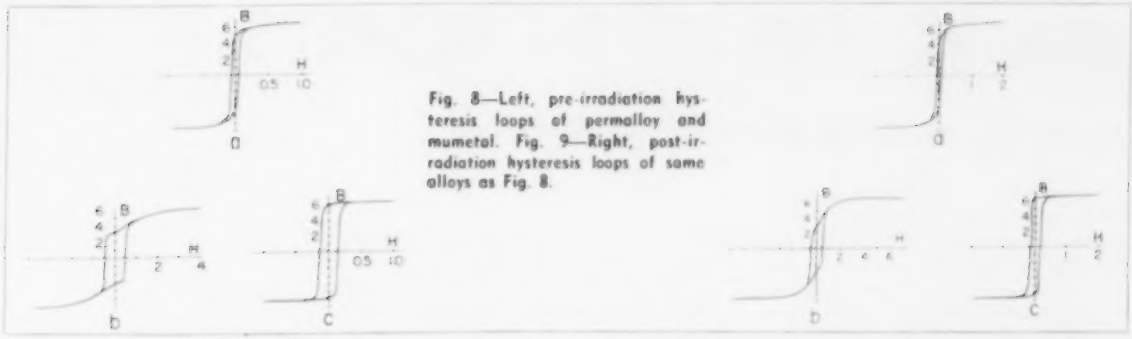


Fig. 8—Left, pre-irradiation hysteresis loops of permalloy and mumetal. Fig. 9—Right, post-irradiation hysteresis loops of same alloys as Fig. 8.

hysteresis loop is obtained. The new hysteresis loop will, of course, have different values of coercive force and remanence consistent with the values of cubic anisotropy and magnetostrictive constants of the ordered alloy.

Additional experiments

With the above considerations in mind, Schindler and Salkovitz[6] carried out additional experiments in which the samples were irradiated in the presence of a saturating magnetic field. The samples used were commercially-available toroids, mainly of iron and nickel alloys of the following compositions: 4 pct Mo-79 pct Ni-17 pct Fe (permalloy); 5 pct Mo-79 pct Ni-16 pct Fe; 5 pct Cu-2 pct Cr-78 pct Ni- 15 pct Fe (mumetal); and 48 pct Ni-52 pct Fe

Two samples of each material were wound with appropriate B and H coils and installed on the same sample holder. Pre-irradiation 60-cycle hysteresis loop measurements were taken, and the samples were then irradiated at the Brookhaven reactor for two weeks. This short irradiation time was chosen so that only short-range ordering could occur. The total integrated flux for these samples were:

ϕ fast $= 1.25 \times 10^{18}$ to 3.0×10^{18} nvt
ϕ epi $= 2.6 \times 10^{17}$ nvt
ϕ thermal $= 5.9 \times 10^{18}$ nvt

The temperature during irradiation was kept relatively constant, with the limits being between 80° and 120°C for the various samples. During irradiation, a saturating, magnetizing direct current was passed through the H coil of one sample of each pair. The field produced was in the same direction as the field applied during hysteresis loop measurements. After the irradiation, the hysteresis loops of each sample were taken again.

Figs. 8 and 9 show the pre- and post-irradiation hysteresis loops of permalloy and mumetal. The pre-irradiation loops are marked a, while the post-irradiation loops are the curves marked b and c. Loop b is the hysteresis loop of the sample irradiated in the absence of a magnetic field, while loop c is for the sample irradiated in the presence of a saturating magnetic field applied to the toroid. In both cases, loop b is similar to results previously observed, i.e., decreased remanence, increased coercive force, and decreased permeability. (Note: to saturate the irradiated sample, a field several times that of the pre-irradiation saturing field was required.) In loop c, a strikingly different effect was observed, namely rectangular loop characteristics were obtained with both the coercive force and remanence increasing.

These results are consistent with the suggestions previously made that neutron irradiation causes ordering in Ni-Fe alloys. The modified hysteresis loops reflect a change in the uniaxial anisotropy of the state of final order. In the case of samples irradiated for short times in the absence of an applied field, the resulting directional short-range ordering causes constricted hysteresis loops. However, in the case of samples irradiated in a magnetic field, the resulting directional ordering causes rectangular hysteresis loops. It would also appear that for the samples irradiated in the absence of a magnetic field, long-term irradiation causes the formation of the Ni_3Fe superlattice. The directional short-range ordering and resulting magnetic anisotropy then decreases and the normal-shaped hysteresis loop is obtained. These results are of great significance in development of theories concerning the relationships between the degree of order, magnetic anneal, and resulting magnetic properties. In addition, it should be noted that improved materials have been obtained. To date, it is impossible to obtain 2 mil permalloy tape by any known combination of thermal and mechanical treatment which has the rectangular loop characteristics of this irradiated material.

Conclusions

It has been demonstrated:

1) That there are magnetic materials which are radiation resistant. These materials do not have exciting magnetic properties and, conversely, are stable to most treatments;

2) That alloys which do have enhanced magnetic properties such as the permalloys are very susceptible to irradiation;

3) By making detailed study of the phenomena, it has been possible to inhibit damage in some cases and, more important, to produce better magnetic materials;

4) And, finally, radiation studies may be used as a physical tool to study materials in magnetic states hitherto unobtained in some of these materials.

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BRINGING AIME TO THE MEMBERS —

A review of three regional conferences

In an effort to bring the AIME to members, who—all too frequently—find themselves unable to attend the various national gatherings of the three Societies and their divisions, encouragement has been given to the organization of regional conferences. During the months of April and May, three regional AIME meetings were held in widely scattered parts of the country: the Southwest Metals and Minerals Conference in Los Angeles, the Pacific Northwest Metals and Minerals Conference in Portland, Ore., and the New England Regional Conference in Boston. In each case, while the majority was made up of AIME members from that region, strong participation on a national basis was in evidence. And at least two familiar faces were seen in the corridors and at the dais of each of these conferences: The Metallurgical Society's President, Carleton C. Long, and AIME's President, Joseph L. Gillson. Our applause goes to them for their unstinting devotion to the AIME.

1. Southwest Metals and Minerals Conference

Ambassador Hotel, Los Angeles April 21-23

Meeting simultaneously with the Southwest Metals and Minerals Conference were the Acid Converter and Basic Oxygen Steel Committee and the Western section, National Open Hearth Steel Committee. Thus, there was plenty of opportunity for metals men of all persuasions to participate.

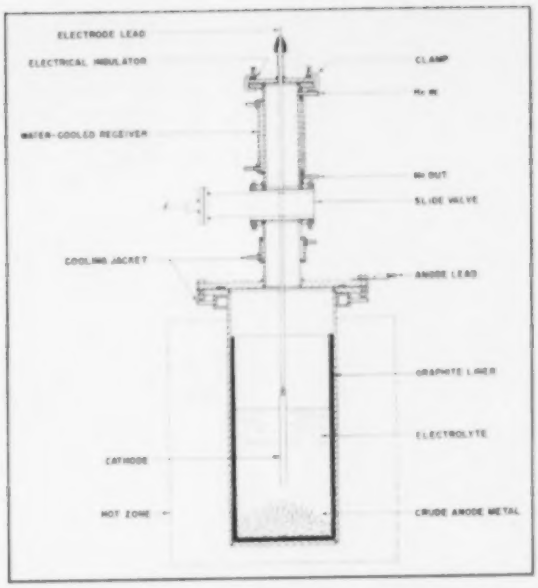
The garden-like setting of Los Angeles' Ambassador Hotel with its luscious outdoor swimming pool would have been inducement enough for attendance at the 1960 AIME Southwest Metals and Minerals Conference, but the outstanding nature of the program was the pièce de résistance which brought attendance above the 500 level. Quite a success it would be called.

Beryllium

The Conference theme, Metals and Materials for the Space Age, was well illustrated in a half-day session on Beryllium Metallurgy and another on Materials for Space Vehicles. The beryllium symposium began with a discussion of *Recent Developments in Beryllium Technology* by A. R. Kaufman and S. H. Gelles of Nuclear Metals Inc. They emphasized the effect of impurities on the brittleness of beryllium and the metal's response to heat treatment. Another paper on the program, *Beryllium Research in Missile Development*, by C. O. Mathews of Lockheed Missile div., concerned improved formability and toughness in missile-quality beryllium. Also coming to light were research projects in electron beam melting of ingots, primary mechanical working, direct rolling of powder composites, zone refining, and forming and joining development. A mining session, held simultaneously, introduced D. H. Baker, Jr., of the Henderson, Nev., station of the US Bureau of Mines. He gave a description of fused salt bath entitled *Electrolytic Beryllium*. These and other papers comprise a wealth of information on beryllium which JOURNAL OF METALS expects to present, along with other papers, in a special beryllium issue, scheduled for later this year.

Space vehicles materials

The Materials for Space Vehicles session got underway with a dissertation on *Materials Problems in Tube Bundle Engine Development* by Robert Boundy of California Institute of Technology's Jet Propulsion laboratory. He emphasized the development of stainless steel tubes and the brazing of a chamber, and also touched on the transition from torch silver brazing to furnace nickel-base alloy brazing. Robert Lipkis of Space Technology Laboratories Inc. followed with a paper on *Materials Problem in Temperature Control of Space Vehicles*. Mr. Lipkis pointed out that "materials should be relatively unchanging when exposed to stresses of the space environment, since active temperature control system can accommodate property changes only up to a point. There is a great need to reduce thermal paths with the vehicle," he noted. "Materials with a high thermal-conductivity:density ratio thus become candidates for structural parts and outer vehicle shells. Lithium, beryllium, and aluminum are most suitable," the author noted, but "a heavy penalty is paid in this regard by alloying such materials for strength and manufacturing purposes. Certain parts of a satellite suffer several temperature drops in eclipses, for instance, the solar cell paddles and large radiator areas. They must withstand repeated cycling to temperatures below −200°F. High temperatures will be encountered in various power plant systems, i.e., the focus of solar



Cell used to prove the feasibility of fused-salt electrorefining of metals by the U.S. Bureau of Mines.

collectors, where the temperature will cycle over wide ranges—at least in the case of earth satellites."

E. C. Burke of Lockheed Missile div. considered *Satellite Vehicle Materials in the Space Environment* by attempting to identify various deleterious effects . . . summarizing present knowledge concerning them . . . and drawing conclusion regarding their importance for satellite vehicles. L. D. Jaffee of California Institute of Technology concluded the program with a discussion of the *Effect of Space Environment on Space Materials.*

Electrowinning W and Mo

A particularly significant paper for metallurgists was given in one of the mining sessions by J. B. Zadra of Reno Metallurgy Research Center, US Bureau of Mines. His topic: *Electrowinning of Tungsten and Molybdenum from Sheelite.* Following is an excerpt from the paper:

Tungsten and molybdenum metals have been produced by fused-bath electrolysis of sheelite in an alkali phosphate or borate bath using externally-heated, circular graphite cells and graphite, steel, or tungsten rod cathodes. Operating temperatures range from 950° to 1050°C; current density is from 7 to 57 amp per sq dm; and yields from 400 to 650 g of tungsten per kw hr. Current efficiencies were satisfactory for all current densities investigated.

Crystal size and purity of the tungsten metal produced are functions of temperature, current density, and amount of impurities in the electrolyte. Deposited crystals vary in shape from spherical grains to clusters of dendritic, hexagonal needles; and in size from 44 to 570 μ. The purity of the tungsten metal produced ranges from 99.7 to 99.94 pct.

Under controlled conditions, the molybdenum in the mineral powellite, commonly associated with sheelite, is separated from the tungsten in the same bath in a one-step operation. The decomposition voltage of molybdenum is much lower than for tungsten. At a low voltage, molybdenum deposits first. By exchanging cathodes and increasing the voltage, tungsten is deposited on the second cathode. In using this technique, the molybdenum metal deposited during 1.5 hr of electrolysis contained 98 pct Mo and 2 pct W. The molybdenum metal produced was also dendritic and in a size range of less than 44 μ.

Electrolyte reagents are economical and common; approx 77 pct of the reagents in the spent electrolyte are water soluble and are regenerated by crystallization. Power consumption is small, averaging 1 to 2 kw per lb of tungsten produced.

Another paper of interest was *Electrolytic Vanadium and Its Properties* by H. D. Ramsdell, also of the Reno Bureau of Mines operation. In his paper Mr. Ramsdell explains that, "In the past few years the Bureau of Mines has developed and proved the technical feasibility of fused-salt electrorefining of metals such as titanium, beryllium, hafnium, and zirconium to remove gaseous and certain other impurities. Fused salt refining of vanadium was considered because the gaseous impurities nitrogen and oxygen have serious effects upon vanadium's physical properties. Commercially, the production of low nitrogen-oxygen vanadium is an expensive, complicated, and time-consuming process by any of the standard reduction techniques. Since the fused-salt electrorefining technique has been scaled-up to a 10,000 amp cell, the technique has offered a means for improving the quality of technical-grade vanadium at something approaching a commercial scale.

"The 12-in. diam electrolytic cell used in the vanadium tests was identical to those used for refining titanium metal, except for a graphite liner used to minimize iron contamination of the bath. Commercial vanadium (99.5 pct V) crushed to—½ in. was charged to the bottom for the anode. The cathode was a ¾ in. diam iron rod. Vanadium chloride was applied to the sodium chloride bath through the reaction of chlorine gas and a small amount of admixed hydrogen chloride, with the granular anode metal contained in the cell bottom.

"A total of 127 cycles or runs were made in the cell before the graphite liner failed, terminating the operation. The first three cycles were made for the purpose of conditioning the electrolyte.

The metal product from the fourth run tested 95 R_B in hardness, and there was a progressive improvement in succeeding cycles, with a hardness as low as 35 R_B on the +35 mesh fraction. Vanadium metal produced in the following 60 cycles of operation was separated into four sieve products, with approx 72 pct of the metal coarser than 80 mesh. The total deposited metal had a weighted average hardness of 52 R_B.

Coarse crystalline metal was produced at applied voltages between 0.4 and 0.7 v. The bath contained 3.0 pct V as the dichloride and was at a temperature of at least 800°C . . . A typical range of analyses of the refined metal was 0.01 pct C, 30 to 500 ppm Fe, 0.04 to 0.10 pct O, and 0.002 pct N.

"After arc melting, the 10-g buttons were easily cold rolled to 0.005-in. sheet—a total reduction of 98 pct—with no anneals. Electro-refined vanadium shows a hardness increase of approx 55 Vhn greater than its original annealed hardness when cold-reduced 65 pct. The return to pre-deformation hardness occurs with annealing temperatures in the 900° to 1000°C range, which corresponds to the temperature range for the beginning of grain growth."

Summing up, Mr. Ramsdell said that, "the fused-salt electrorefining technique offers a feasible means of controlling the quality of gaseous impurities such as oxygen and nitrogen in vanadium metal. The study also has shown that the properties of electrorefined vanadium are considerably different from those exhibited by commercially-available vanadium, because of the reduction of impurity content. The oxygen content, more than any other single impurity, showed the most marked affect on hardness, strength, and workability."

Luncheons

Two Conference luncheons were held in the Biltmore Hotel's mammoth Cocoanut Grove. At the first of these, AIME President Joseph L. Gillson spoke on *Industrial Minerals in the Southwest*. G. Mervin Ault of the National Aeronautics and Space Administration spoke on *New and Improved Materials—The Key to Space Flight*, during the second luncheon.

Mr. Ault pointed out that in the period immediately following World War II this country's experience with high-temperature materials was limited to the development of turbine buckets used for jet engines. Research on better high-temperature materials for turbine buckets has resulted in a gain of temperature resistance from 1400° to only 1850°F. Superalloys used for turbine buckets have been limited to nickel-base and cobalt-base alloys.

In materials research for high-temperature service, we have been operating with equipment developed for the lower melting solids, Mr. Ault noted. Hence, when we fabricate these newer materials we are really cold working them rather than hot working them.

In the study of materials for missiles, and specifically, in studying the re-entry problem, the leading edge temperature is a function of the speed of the missile. Studies have indicated that materials such as fiberglass-reinforced plastics give satisfactory service for the leading edge of the missile because of superior heat absorption, the missile man explained. This is because of the ablating surface of reinforced plastics. They handle the heat absorption problem by fusion, vaporization, and re-radiation; hence, are leading candidates for nose cones.

Mr. Ault mentioned the strength tests which have indicated iron whisker strength up to 2,000,000 psi. However, these values are not maintained in large dimensions of the same materials. One solution appears to be the development of composite materials from metal fibers.

Acid Converter - Basic Oxygen Steel Meeting

Starting one day prior to the Southwest Metals and Minerals Conference was the annual meeting of the Iron and Steel Division's Acid Converter and Basic Oxygen Steel Committee. And world-wide was the representation it drew . . . with metallurgists from Japan, Austria, Germany, Sweden, Canada, and the United Kingdom.

The first day, Wednesday, April 20th, was marked by a visit to Kaiser Steel Corp.'s $23-million LD, basic oxygen steelmaking plant at Fontana, Calif. Impressive indeed was this ultra-modern installation . . . with LD vessels making 109-ton heats in a 1 hr tap-to-tap cycle, from a charge made up of approx 25 pct scrap and 75 pct hot metal—although some heats use ore additions. Burnt lime, fluorspar, and mill scale are used as fluxes in the operation, in which 7000 cu ft of oxygen per min is blown at a lance pressure of 130 to 135 psi. The vessels—only one of which was in operation—generally produce mechanically-capped, low-carbon steel for Kaiser's structural, welded pipe, and sheet mills. Nominal capacity of the three-converter plant is 1.4 million tons, with a potential of 2 million tons annually.

That evening the Committee joined the Western section, NOHC, for dinner in the Ambassador Hotel. J. E. Tredennick of Kaiser Steel was dinner speaker, discussing *Basic Oxygen Steelmaking*.

Thursday, April 21st, included a full day of round-table discussion: Acid Converter Steelmaking in the morning, and Basic Oxygen Steelmaking Processes in the afternoon.

The three-day meet concluded Friday morning, April 22nd, with a technical program consisting of three papers: *Investigation of Bessemer Converter Smoke Control* by A. R. Orban, R. B. Engdahl, and J. D. Hummel of Battelle Memorial Institute; *The Acid Bessemer Oxygen Steel Process* by G. M. Yocum, Wheeling Steel Corp.; and *The Physical Chemistry of Oxygen Steelmaking* by D. L. McBride, U. S. Steel Corp., which was published in the July JOURNAL OF METALS.

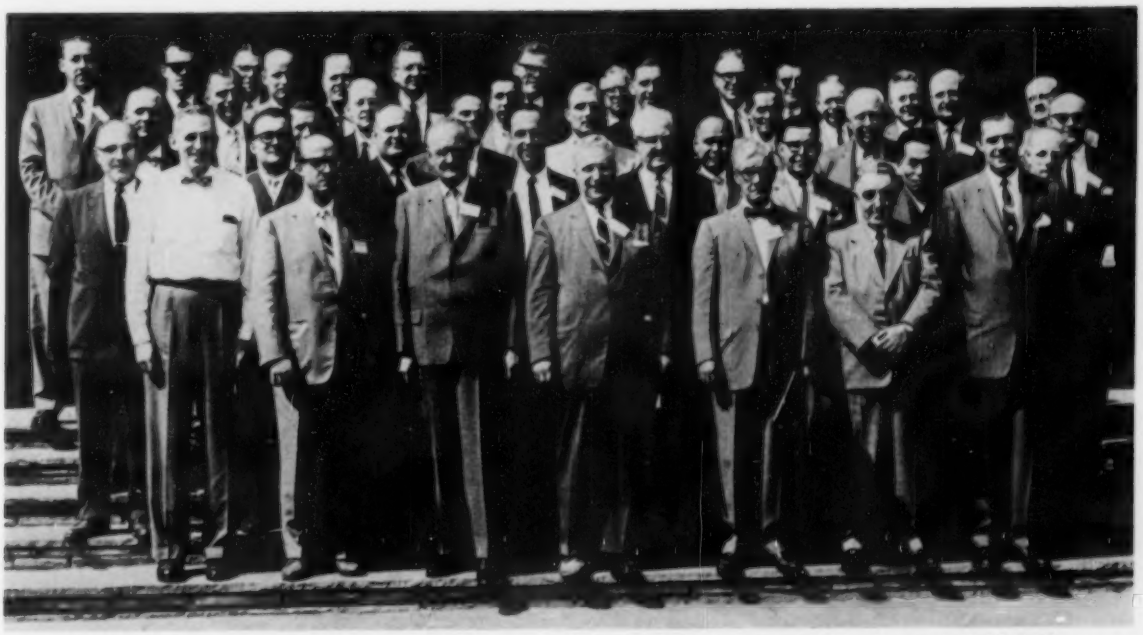
2. Pacific Northwest Metals and Minerals Conference

Sheraton Hotel, Portland April 28-30

Again, the surroundings were spacious in the setting of Portland's new Sheraton Hotel . . . again an excellent program was arranged . . . and again attendance broke the 500 mark. For metallurgists there were two full days of interesting sessions, as well as plant trips and social events.

Refractories

Sessions began on Thursday morning with *Refractories for the Aluminum Industry*. In this paper James E. Lorenz of Kaiser Aluminum & Chemical Corp. told of tests designed to evaluate molten alloy attack and thermal shock damage on commercially-available 70 to 90 pct alumina brick. A correlation between the laboratory test and plant service was established by installation and evaluation of test panels in the melting hearth of plant re-melt furnaces. Refractory performance below the metal line in aluminum melting furnaces was found to be related to alumina content and bond type, the latter affecting both the resistance to attack and thermal shock damage.



AIME Acid Converter and Basic Oxygen Steel Committee at Kaiser Steel Corp.'s Fontana, Calif., plant on April 20, 1960.

A paper by W. L. Peskin of The Carborundum Co. pointed out that while the aluminum industry operates its furnaces at comparatively low temperatures, it has many problems for which ordinary refractories (developed over the years for other purposes) leave something to be desired. This deficiency of ordinary materials, coupled with the need for more economical production of high-quality metal, led to the investigation and evaluation of special refractories, such as silicon carbides, silicon nitride, fused alumina, mullite, zircon, and fibrous ceramics made from alumina-silica fusions.

J. E. Dore of Olin Mathieson Chemical Corp. noted that while the selection and proper use of refractory lining materials is important in determining the life and serviceability of aluminum melting and holding furnaces, of equal importance is the method of furnace operation. In his paper he discussed those operating variables and procedures which have the most pronounced effect on furnace life and performance.

The all-day session concluded with papers on *Refractories for Carbon Baking Furnaces* by C. F. Wenrich, Harbison-Walker Refractories Co.; and *The Effects of Processing and Composition Variables on Refractories Used in the Aluminum Industry* by W. J. Meid, Lindberg Engineering Co.

Extractive metallurgy

Thursday also saw an interesting morning session on extractive metallurgy, which began with a discussion of *The Current Status of the Direct Reduction of Iron Ore* by H. W. Lownie, Jr., Battelle Memorial Institute. Supplying commentary on a series of slides, Mr. Lownie traced the general lines of development taking place in direct reduction . . . followed with more detailed information on electric furnace processes and the economic merits of prereduction devices . . . and concluded with cost estimates for various ironmaking processes in the Pacific Northwest.

This paper was followed by a discussion of *Recent Developments in the Strategic-Udy Processes* by Murray C. Udy; and a description of *Production of Ferronickel at Riddle, Ore.*, by E. Coleman. This last named paper followed along the lines of that presented on pp. 197-205 of the March JOURNAL OF METALS.

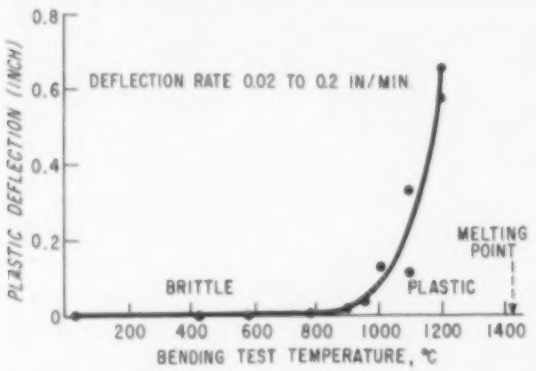
FWS

The session concluded with a paper describing techniques being developed by the US Bureau of Mines' Albany Metallurgy Research Center into the extraction of alumina from the area's ferruginous bauxites. Such a development, if successful, would have an economic impact on aluminum production in the Pacific Northwest, since the region now depends upon alumina shipped from the Caribbean or distant points in the Pacific. L. H. Banning delivered the paper, which described techniques for smelting the ferruginous bauxites to produce a leachable slag and pig iron . . . the utilization of the Bayer extraction process on this raw material . . . and double leaching technique. The most promising results were obtained in the double-leach process, for up to 85 pct of the alumina was recovered from raw materials containing as much as 16 pct SiO_2. Work is continuing on this method in order to determine optimum conditions for the various unit operations.

Ferrous and physical metallurgy

Thursday afternoon was given over to an iron and steel session devoted to New Fabrication Techniques. S. S. Jenkins, Jr., E. I. du Pont, described techniques his company is developing for using flexible sheet explosives in the impact hardening of manganese steel, used in such things as railroad switch units. An excellent global view of *Recent Studies in the Explosive Working of Metals* was presented by John Pearson of the US Naval Ordnance Test Station, China Lake, Calif. JOURNAL OF METALS will present this paper in a forthcoming issue. The session ended with a description of another interesting technique,

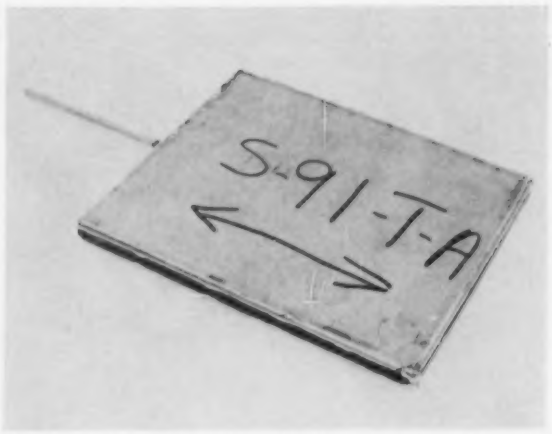
Above, a 6x6-in. piece of silicon about 0.050 in. thick which was rolled in a molybdenum jacket at 1325°C; the jacket has been largely removed by etching. Below, plastic deflection by bending of silicon samples—typical of data used in selecting metal-working temperatures. From a paper by D. W. Lillie, presented at New England Regional Conference.



chmeical milling, by J. D. Barton of Turco Products.

Friday's technical sessions called for Physical Metallurgy in the morning and Heat Resistant Alloys in the afternoon. Included in these sessions was a paper by E. F. Baroch describing *The Production of Refractory Metals Using the Electron-Beam Melting Technique*. It gave details of production techniques used at Wah Chang's Albany, Ore., plant for the melting of columbium and other metals and alloys used on an industrial scale. The commercial possibilities of this melting-refining technique appear most interesting, and will appear in a future issue of JOURNAL OF METALS.

Also included in Friday's sessions was *A Liquid Cooling System for Consumable Electrode-Arc Furnaces*, a paper by D. E. Cooper and E. D. Dilling, which followed the description of the process as it appeared in the February issue of JOURNAL OF METALS, pp. 149-151. *A Laboratory Casting Furnace for High Melting Point Metals* was based on the Albany Metallurgy Research Center's laboratory tool for studying the application of the skull-casting technique to high-temperature metals. The consumable-electrode furnace is equipped with a water-cooled copper ladle, which is a tilt-pour or over-the-lip type having a volume of approx 30 cu in. and providing up to 20 cu in. of molten metal. Castings of



Titanium clad assembly of F-48 columbium alloy after welding and before pinch-off of evacuation tube.

various reactive and refractory metals, including zirconium, titanium, hafnium, columbium, molybdenum, tantalum, and tungsten, have been produced. A description of the installation will appear in a later issue of JOURNAL OF METALS.

The Pacific Northwest Metals and Minerals Conference also included sessions on geology, industrial minerals, and gold and money, as well as plant tours, luncheons, and other social events.

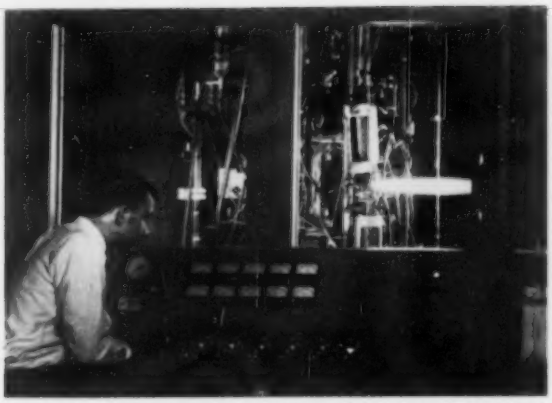
A real treat came on Friday evening, following the annual banquet, when Joseph L. Gillson, AIME's President, gave an illustrated talk on *Pre-Columbian Ruins*. Taking his listeners through Mexico and Yucatan with a series of fascinating colored slides, he described various major civilizations which have been unearthed, and gave some delightful—although somewhat gruesome—sidelights on the people who lived there. Stimulating as this was, the evening was destined to go on further, as the band took up the strains of the latest *two-step*, *hop*, or *pongo-pongo* which was requested. Finally, in the early hours the next morning, somewhat exhausted, Mr. & Mrs. Metallurgist gave up the last trumpet call to the Conference, feeling that somehow it was really worth it all.

3. New England Regional Conference

Statler-Hilton Hotel, Boston May 26-27

Spanning the North American continent was the next step in our frantic effort to keep up with AIME's regional conferences. The schedule called for arrival in Boston for the 14th Annual New England Regional Conference.

With excellent attendance, sessions got underway on High Energy Rate Forming on Thursday morning, Special Metalworking Processes that afternoon, and Extrusion on Friday morning. These sessions were arranged so as to give the basic theory first, then papers describing the application of the concept, and concluding with a panel discussion on the topic. This method of organization had proved successful in previous conferences, and was undoubtedly the key to a most stimulating series of sessions at this year's New England Regional Conference.



One of the largest plasma generation facilities in the US—the 15 megawatt arc wind tunnel of Avco Research and Advanced Development div. Visited by New England Regional Conference.

High energy rate forming

With a clear idea of the theoretical concepts of high-energy rate forming in mind, thanks to a discourse by R. S. Davis of Arthur D. Little Co., registrants listened to J. S. Rinehart, Colorado School of Mines, discuss explosive forming. Professor Rinehart pointed out that explosive forming could be described under two sub-topics: utilization of high explosives; and utilization of low explosive. The latter are similar to those used in guns or solid-fuel rockets and burn from the inside out with a greater than proportional increment of increased power for an increment in the quantity of explosive used. Thus, although the pressures are lower with this type of explosive, they are not as readily controlled, and the weight of the explosive used is critical. For high explosives, the weight of the explosive is less critical than the distance from the charge to the work piece.

Professor Rinehart described a number of explosive-metal systems, including a cylindrically-shaped explosive with one end in intimate contact with the metal. The work done by the explosive in such a case does not depend upon the length of the explosive, and for lengths beyond 2.5 x diam of the explosive, no further work can be obtained. Layer-type explosives, such as those developed by du Pont, can be applied directly to the working piece, and the result can be either to harden the surface or shape the piece. Applications have been made in the hardening of shovel blades and engraving or embossing metal plates. Welding of metal shapes and compaction of metal powder are two other areas in which explosive forming is being used. In a further application, explosives can be used in splitting metal shapes.

The third paper of the session was by J. J. Douglass of du Pont, who discussed *Forming Practices With High Explosives*. Prefacing his remarks with the advice that explosive forming should be considered as a forming technique designed only for those difficult-to-form metals and shapes incapable of being handled by other techniques, Mr. Douglass discussed the various explosive possibilities which could be used. A blasting cap in a water container can be used to shape a cylindrical part or emboss a flat sheet, while a mild detonating fuse and *Primacord* were the next most powerful explosives to be employed. Sheet explosive, either single or stacked, can be used for flat shapes. Dished head shapes can be formed from a flat plate by means of stacked discs of sheet explosives, but in this case the female mold must be under vacuum. Finally, head forming can be accomplished with ring charges of sheet explosives.

The final paper of the High Energy Rate Forming session was *Applications of High Energy Rates to Manufacturing Techniques* by E. W. Feddersen of Convair. Mr. Feddersen explained that Convair has given up the use of explosive forming except where absolutely necessary. Convair is applying high energy rate to the deformation of materials outside the framework of traditional types of heavy machinery. Three methods are being used: electro-magnetic, hydro-electric, and pneumatic-mechanical. Convair practices the first named in the swaging of parts subject to high-velocity vibration in jets, since electro-magnetic deformation does not produce cold working of the metal. Hydro-electric forming is used for bulging and shearing operations from preformed hollow bodies by Convair and two other US firms. Pneumatic-mechanical forming, or *Dynapac*, makes use of stored compressed gas. It has a number of applications, including the extrusion of metal into complex shapes unobtainable by other techniques.

Other sessions

The afternoon session on Special Metalworking Processes produced several interesting papers, including *Future Metal Processing Problems* by D. W. Lillie, General Electric. Discussing the handling of high-temperature materials, Mr. Lillie outlined three methods of hot working. First, the metal ingot can be canned in another metal, i.e., columbium canned in molybdenum. The can is extruded into a sheet bar while hot, cross rolled, then reclad if further hot working is required. Cold rolling can be accomplished without such precautions. A second method for handling such metals during hot working operations is to surround the working tool with an inert atmosphere in a closed container or furnace. The third possibility is to put the whole fabricating facility in an argon atmosphere, with operators in specially-constructed suits supplied with oxygen. This was done in the *InFab* unit recently put into operation by Universal Cyclops and described in some detail in another article in this issue. Mr. Lillie concluded by discussing techniques for working brittle materials. The properties of the metal or alloy at various temperatures should be known with some precision in order to have the correct temperature range for working, he pointed out. Slow rates of deformation can be helpful. Pure silicon has been hot worked in this manner at the narrow temperature range of 1300° to 1350°C.

* * *

The New England Regional Conference also included an excellent session on Extrusion, as well as a luncheon and cocktail hour. Friday afternoon saw a trip through the Avco Research and Development div. laboratory at Wilmington, Mass. At the same time, the Board of Directors of The Metallurgical Society met at the Statler-Hilton.

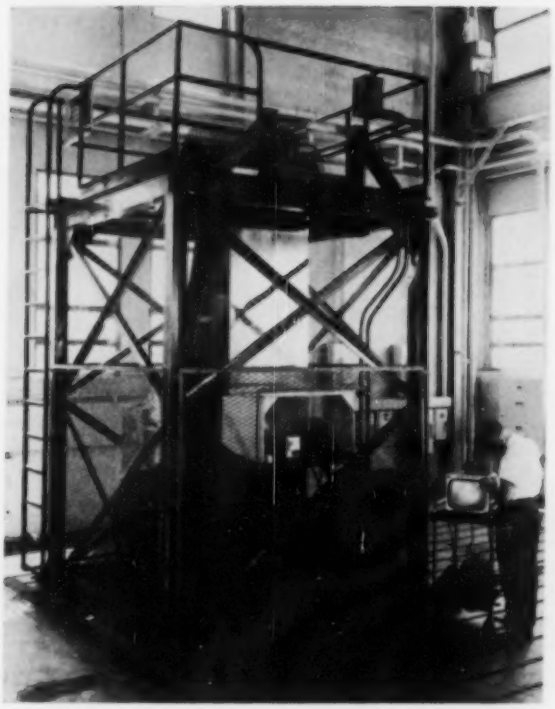
Thus ended the 14th Annual New England Regional Conference. And as we trudged . . . somewhat wearily . . . back to our hotel in Boston, we felt that these regional meetings had indeed been successful in bringing nationally-known authorities to various local areas, as well as bringing local people together to talk over their metallurgical problems . . . hence bringing AIME to the members.

U.S. STEEL OPENS ELECTROMECHANICAL BUILDING

Developing new controls and instrumentation from simulated blast furnace.

A new Electromechanical Building at U. S. Steel Corp.'s Monroeville, Pa., Research Center was recently dedicated. The Building will house the division of applied research's electromechanical laboratories.

"The new laboratories will be dedicated to the development and application of control systems for new and existing processes in all steelmaking functions, and will search for better methods of controlling the chemical and metallurgical properties of our products," explains J. B. Austin, administrative vice president—research and technology.



Stroboscope-TV study of tin's crystal formations to improve quality control.

One of the first problems the electromechanical group is attacking is the design of controls and instrumentation that will go into the Research Center's new pilot blast furnace. The furnace—scheduled for completion this fall—will be the most advanced of its type in the world, according to Dr. Austin. In an accompanying picture, J. H. Wilson, assistant technologist in the ironmaking laboratory of the Electromechanical Building, is shown working on a simulated blast furnace. Mr. Wilson is tabulating temperature changes, as recorded on the instrument centered on the table above the small blast furnace. On either side of the furnace are miniature radiation devices aimed at tuyere peepholes at the base of the furnace. This bench-scale experiment is exploring the possibilities radiation devices hold for measuring temperatures in the combustion chamber of a full-scale blast furnace. Full-scale blast furnace experimentation of this type is presently underway at U.S. Steel's Edgar Thomson works, Braddock, Pa.

The electromechanical laboratories also have a vital role in thin tin-plate research. Such tin plate is about half the thickness of anything now used in can making. "Thin tin is still in the development stage," Dr. Austin comments. "We are actively exploring its possibilities . . . at the Research Center, but from the work we have done thus far, we believe the lighter tin plate to be an economically sound product for can manufacture."

Pictured is a television receiver which monitors tin sheets' crystal formation. By studying these formations, researchers hope to discover what correlation, if any, exists between the size of tin crystals and the corrosion resistance of tin plate. In addition to the television camera (center) and the receiver, the 14-ft 9-in. tall laboratory test stand is equipped with a stroboscope (next to camera) which emits a high-density, pulsating light. Periodic interruption of the light source stops tin-plate speed for the camera—a speed which on a full-scale tinning line may reach 1200 fpm. Passed from the camera, the image is captured in a special storage tube which, in turn, permits the picture to remain on the screen up to 30 min for close examination. A test run, based on this experiment, is presently being conducted on tinning lines at U. S. Steel's Tennessee Coal and Iron div., Birmingham, Ala.

Dr. Austin stated that the ultimate goal of the new laboratories' work is 1) to obtain ever higher quality; and 2) to improve the yield of U. S. Steel's mills. He cited the corporation's recently-completed structural mill in the Chicago area as an example of the type of work carried out by electromechanical research. "In this new mill," Dr. Austin said, "there are modern, push-button controls. Designed for electronic program control, the mill will operate uniformly, resulting in much greater efficiency in rolling operations and improved quality of product. The entire rolling schedule may be put on a punch card. The operator can then insert the card into a card-reader, and thereby initiate the rolling sequence as he pushes a button. Semi-automatic operation is also available to allow the operator to initiate each function manually, if desired or necessary."

Electrochemical research will also be carried out on projects ranging from problems in materials handling to the development of automatic devices. "For example," said Dr. Austin, "in raw materials, we are interested in developing methods for the continuous sampling and analysis of iron ore and then in automatic measurement of its weight and rate of flow. In the area of inspection, we are working on new or improved quality-guarding devices which promise to insure the production of ever-finer products by all our plants."

In product research, Dr. Austin ennumerated the following projects: suitable steels for nuclear reactors, missiles, space vehicles, and manned aircraft. One new stainless steel still under extensive testing has shown a room-temperature tensile strength of 250,000 psi, says Dr. Austin—more than four times the strength of ordinary carbon steel.

One result of applied research alluded to by Dr. Austin is *sandwich* rolling. Sandwich rolling involves the enclosing of stainless steel in a case of carbon steel prior to rolling, making possible production of much wider stainless steel in a broader range of thickneses than available heretofore.

"In effect," Dr. Austin said, "U. S. Steel's applied research program embraces a complete pilot-scale steel mill with its sintering line for research into iron ore beneficiation . . . a coking plant . . . chemical recovery plant . . . minature blast furnace . . . steelmaking furnaces . . . hot and cold rolling mills . . . vacuum casting facility . . . electro-tinning, vinyl coating, and galvanizing lines . . . and enameling furnaces. Each of these pilot facilities provides scores of research teams with the equipment necessary to their efforts."

ITALY INVESTIGATES DIRECT REDUCTION OF IRON ORE

With initial research devoted to the utilization of natural gas, Italy is now pursuing a program based on gas manufactured from solid fuels. Reduction will take place in a shaft-furnace pilot plant being built in Genova and financed by the European Coal and Steel Community.

by Antonio Scortecci

THE Italian iron and steel industry, risen from the ruins of World War II, has shown a remarkable growth during recent years. The production of steel has exceeded the highest pre-war level—reaching 6.8 million metric tons in 1957 as compared to 2.3 million tons in 1938.

Italy has, thus, become the fourth greatest steel-producing country in Europe. And the Italian steel industry is now able to meet steadily-increasing home market demands as well as assuring the export of steel products in competition with the most modern foreign industries. Since Italy must import most of the raw materials used for iron and steel production—ore, scrap, and chiefly coking coal—the export of industrial products is absolutely necessary in order to attain equilibrium in the Country's balance of payments.

The problem of exporting in the field of free competition can be successfully tackled only by the most modern industrial plants. This unavoidable necessity of modernization has been clearly understood by the whole Italian iron and steel industry and particularly by the largest Italian group in this field, Finsider, which, ever since the end of the war, has continuously improved the technical and economic efficiency of its plants.

Established in 1937, Finsider is a holding company whose capital is mostly controlled by the Italian government. It coordinates and controls some technical aspects of a group of five large steel firms with a total of 23 plants . . . several commercial, mining, cement, and transport concerns . . . one firm for the production of refractories . . . and about 40 smaller firms working in mining, mechanical, electrical, shipping, commercial, and financial fields.

The Istituto Siderurgico Finsider

Finsider, during recent years, has not limited its activities to the reorganization and modernization of plants heavily damaged by the war, but it has also developed an intense activity in helping the firms of the Group in personnel selection and training, and in applied research. These special tasks have been performed by the *Istituto Siderurgico Finsider*.

From 1945 up to the present time, the Istituto Siderurgico Finsider has trained over 500 university graduates who have been selected by their qualifications and through examinations. After a suitable professional training, these young graduates have joined the offices and factories of the Group according to requirements.

In regard to the second task—applied research—the Istituto Siderurgico Finsider has devoted a remarkable effort to the improvement of conventional production methods and to the development of new iron-and steelmaking processes, always closely cooperating in the planning and development stages with production personnel. The main object of this research has been the lowering of raw-material requirements and production costs.

ANTONIO SCORTECCI is director of the Istituto Siderurgico of Finsider at Genova, Italy.

Reduction with natural gas

For several years research in the area of the direct reduction of iron ores has constituted a large part of the activity of the Istituto Siderurgico Finsider.

When natural gas was discovered in Italy in 1951, and there was hope of having large quantities of this important raw material available, the Istituto Siderurgico Finsider developed research plans for the direct reduction of iron ore by natural gas. A mixed committee of experts of the Finsider Group firms and research workers of the Istituto decided on the construction of a pilot plant by a firm of the Group which was already using natural gas in its open-hearth furnaces. Research workers continued at this pilot plant for four years, concluding in 1957.

The research program, as initially conceived, constituted a study of iron-ore reduction by means of all types of reducing gases which could be derived from natural gas. These gases range from hydrogen, obtained by thermal cracking, to mixtures of hydrogen and carbon dioxide, which could be obtained by reforming natural gas with steam or by its partial combustion with oxygen. The program started with hydrogen.

The pilot plant consisted of two alternatingly-operated checker chambers for the preparation of the reducing gas and a rotary kiln for ore reduction. While one of the chambers was being heated by a methane burner for complete combustion, cracking was taking place in the other chamber. Every half hour the operation was reversed. The hydrogen, heated to approx 1100°C and mixed with cracking carbon, passed through the rotary kiln where it met the ore passing through the kiln in counter-current fashion. At the top of the kiln, the gas was burned with air blown in to preheat the ore.

In this plant a large quantity of sponge iron was produced, with the percentage of reduction varying from 80 to 90 pct, depending on operating conditions. The sponge was withdrawn from the furnace, cooled in closed containers, and briquetted prior to being charged into an electric arc furnace for steel production.

After a series of heats, it was concluded that the briquetted sponge is an excellent charging material for electric arc furnaces. It should be noted that, even after several months of storage, the sponge iron was absolutely stable.

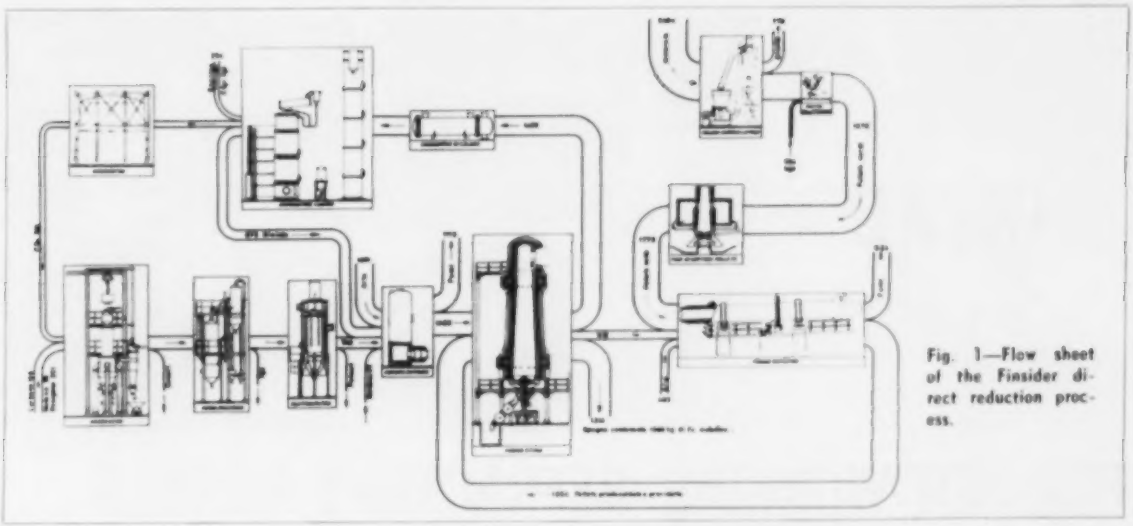


Fig. 1—Flow sheet of the Finsider direct reduction process.

The second stage of this research project should then have been performed. It consisted of the addition of oxygen and steam to natural gas in order to produce a gas containing hydrogen and carbon monoxide. While the project was planned in this sense, it was never achieved since it became known that the quantity of methane in Italy was not as great as had previously been thought. Consequently, natural gas found more suitable uses, its price reaching such levels that its use by the iron and steel industry was no longer economic.

However the problem of ore reduction with smaller quantities of coke still remained important for Europe and chiefly for Italy.

Reducing gas from solid fuels

On the basis of previous experience, the research efforts of the Istituto Siderurgico Finsider were directed toward the production of a reducing gas by the gasification of common-quality solid fuels. This new direction of the research work gave rise to proposals for experimenting with several possible methods of fuel gasification and iron-ore reduction and led to the development of the process now known in the technical literature by the name of the *Finsider Process*. Fig. 1 shows the flow sheet of this process.

According to this process, gasification of solid fuel is performed in a slagging gas-producer by blowing oxygen and adding a hydrogen-supplying gas, such as natural or coke-oven gas. The resulting gas contains approx 70 pct CO and 30 pct H_2. In the gas producer a portion of the gas, coming from the reducing apparatus, can be recycled. The gas is purified from dust and tar, desulfurized, and heated to approx 1000°C by means of a heat exchanger and then blown into a reduction furnace.

In the pilot plant, a shaft furnace is to be used for the final stage of the iron-ore reduction, since it is considered to be the simplest and most suitable equipment for fundamental experimentation. The shaft furnace will be of limited height in order to afford the possibility of temperature regulation, which can provide the best guarantee of continuous production without sticking. Part of the top gas from the reduction furnace is to be cooled, purified, and recycled. The excess gas will be used for prereduction and preheating the charge in a rotary kiln.

In regard to ore treatment, grinding, magnetic concentration, and pelletizing in suitable equipment are forseen. The pellets are to be charged into a rotary kiln where they will be preheated, prereduced, and finally fed into the shaft furnace for complete reduction.

European-financed pilot plant

This second Finsider direct-reduction process, unlike the first which was based on natural gas, makes use of gas from any kind of coal, gassified with oxygen. A variable quantity of natural gas or coke-oven gas may be added.

The problem of the shortage of coking coal is felt not only in Italy, but it is also a characteristic of the whole of the European Community, and any permanent change in this situation in the near future is not foreseen. For this reason the European Coal and Steel Community (ECSC) has, for some time, sponsored studies and research devoted to lowering blast-furnace coke consumption and the direct reduction of iron ores.

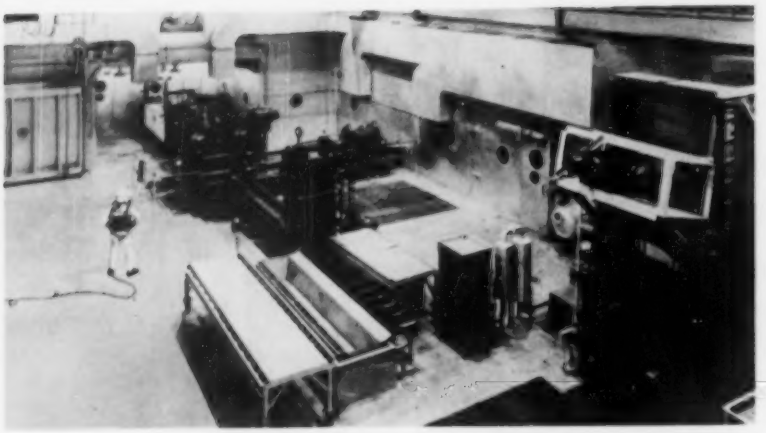
With this in mind, the ECSC is shouldering the largest part of the financial charges of the low-shaft furnace at Liege, Belgium. Similarly, the ECSC Research Committee, considering the Finsider Process as a very important step in the field of iron-ore reduction, has recommended this project to the High Authority of the Community, which has approved financing to the amount of $1 million, corresponding to 80 pct of the estimated expenditure for the construction and operation of a pilot plant.

The pilot plant is to be built in Genova, where the Istituto Siderurgico Finsider has its offices. Planning of the plant and its future experimental program, like all research supported by the ESCS, are followed by a Directory Committee and an Executive Committee comprising experts belonging to all ECSC countries.

This special methodology of international cooperation in research is becoming more widespread. Starting with ironmaking at the low-shaft furnace project, it is now continuing with several other important projects. One of these is the pilot plant being built at Genova.

Through international efforts such as these, it is hoped that considerable technological advancement in iron-and steelmaking can be achieved.

INFAB



FOR HOT-WORKING REFRACTORY METALS

To meet the demands for refractory metals for nose cones, rocket and jet engines, and space vehicles, Refractomet div. of Universal-Cyclops Steel Corp., in conjunction with the US Dept. of the Navy, Bureau of Naval Weapons, designed and constructed the Inert-Fabrication facility at Bridgeville, Pa.

InFab—possibly the key to the industrial-scale hot working of refractory metals—is the name of a new installation designed and built by Universal-Cyclops Corp. in conjunction with the US Navy. At the Bridgeville, Pa., plant, hot working of these exotic metals takes place at optimum temperatures in an inert atmosphere of argon.

At present, operations are in the 4000°-5000°F range—the empirically-determined temperatures for hot working molybdenum and cobalt (85 pct of melting temperatures). Further study is expected to bring about the application of higher temperatures—up to 6000°F—for working tantalum and tungsten. The protective argon atmosphere is effective in deterring both the oxidation and the adsorption of gaseous impurities at these elevated temperatures.

InFab is a plant within a plant, separated from the rest of the Bridgeville, Pa., works. The room's dimensions were planned with the thought of future expansion. At present, the 42x97x32-ft room contains a forging impactor, a rolling mill, and a 10-ton crane. All operations can be controlled from outside the structure or by technicians within. Because of the atmosphere, the technicians must wear a stylized space suit, containing an ample supply of oxygen and a cooling system.

The refractory metals' operation starts with fine metal powders which are fed into a bag loading device. Subsequently, an isostatic compactor is used to compress the powder mix into an electrode shape. Compacted electrodes are passed through a specially-constructed sintering furnace.

The next step involves the melting of the electrodes to form ingots, which are used directly in the InFab process. Melting takes place in a consumable electrode vacuum furnace, which permits gaseous impurities to be held to a few parts per million. The furnace produces 70-in. ingots which may be either 12 or 16.5 in. in diam.

Hot working operations at the InFab plant consist of high-temperature forging followed by rolling. Activities are as completely automatic as possible and are controlled from a console outside the enclosure. Windows of special construction afford the operators protection from harmful ultra-violet radiation emitted from the white-hot metal.

An innovation is the installation of furnaces which move on a car below the impacting dies. The proximity of furnace-to-forge allows forging to take place at approximately furnace temperature. InFab's three high-frenquency induction furnaces can be positioned automatically. They have diameters of 7, 10, and 13 in., respectively, to afford flexible operation.

Forging takes place on a Chambersburg impactor—a horizontal forge driven by compressed argon gas. This two-die operation with die faces 7.5x15 in. provides equal deformation on two sides at a maximum force of 15,000 lb-per-blow.

For rolling operations, two furnaces similar to those used on the impactor are situated at the end of the rolling table. These furnaces may be positioned automatically for feeding forged metal to the rolling table or for returning materials to the furnace.

The 16x36-in., two-high Birdsboro mill resembles a miniature blooming mill; it is equipped with motorized screw-down and automatic feeding equipment. Other features include hydraulic roll balance, antifriction bearings, and front and back motorized tables. In addition, an index device controls the rate of acceptance of stock.

Into the future

InFab operations commenced only recently, so it is too early to discuss operating results. Nevertheless, this new inert fabrication facility bodes well as a means of industrial-scale hot-working of refractory metals. The economics of the operation and the ease and precise means of heating and working these exotic metals would seem to mean lower costs and higher quality. We shall anxiously await a report of the operating results.

1960 AIME Annual Meeting (Cont)

INSTITUTE OF METALS DIVISION

In this issue JOURNAL OF METALS *concludes its review of the technical sessions of the 1960 AIME Annual Meeting. This is not a complete survey of the IMD sessions, since most of them were adequately covered by the publication of abstracts in the January issue. Furthermore, we did not have sufficient volunteer reporters to cover every session. We do wish to thank Messrs. L. Siegle of Sylvania Research Laboratories, J. L. Walter of GE Research Laboratory, R. E. Boni of Armco Steel Corp., H. W. Schadler of GE Research Laboratory, A. D. Schwope of Clevite Corp., N. J. Grant of MIT, and F. L. Vogel, Jr., of Radio Corp of America, for their very kind help in writing these reviews. Unfortunately, space has precluded publication of all of their reports.*

Orientation and Textures

Reviewed by J. L. Walter, General Electric Research Laboratory.

Orientation Distribution of the Surface Plane from Surface Energy Induced Secondary Recrystallization in Silicon Iron Sheets), by J. J. Kramer and K. Foster, Westinghouse Electric Corp.

This paper dealt with the distribution of {100} planes of secondary grains in vacuum-melted silicon-iron containing 3 pct Si. The {100} planes deviated up to 6° fom the plane of the sheet and the largest number of grains had {100} planes at an angle of 1° to the plane of the surface. The authors suggested that thermal etching of the {100} planes lowered the surface energy of these planes and this lower energy was responsible for the growth of these grains. They calculated a decrease of surface energy of about 2 pct as a result of thermal etching of slightly deviating {100} planes.

Observations on Oxide Particles on Surfaces of High-Purity Silicon Iron Sheet, by J. L. Walter and C. G. Dunn, General Electric Co.

In this paper the authors discussed the patterns and number density of oxide particles found on the surface of a sheet annealed in a slightly oxidizing atmosphere. They found that the number of particles per unit area was a function of the orientation of the metal crystals. The particles were shown to be positioned along surface discontinuities such as thermal etch steps and grain boundary grooves. Patterns were altered by interactions with migrating grain boundaries. Position and shape of particles were changed by the moving grain boundaries. Although the particles were known to be transparent and probably amorphous, the exact structure and composition of the particles were not known.

Dependence of Wire Texture in FCC Metals on Stacking Fault Energy, by Norman Brown, University of Pennsylvania.

The author gave a brief review of wire textures in fcc metals. The wire texture is generally composed of {100} and {111} components; metals with higher stacking fault energies have the larger {111} component. He related the formation of the {111} component to the activation energy for cross slip and the stacking fault energy. Comparison of stacking fault energy for various metals vs the amount of {100} component generally showed that as the stacking fault energy decreases, the pct {100} increases and pct {111} decreases. From this relationship the author predicted that lower deformation temperatures would increase the amount of {100} component, while a low rate of deformation would favor development of the {111} component.

Evolution of Textures in FCC Metals. Part II— Alloys of Copper with Phosphorus, Arsenic, and Antimony, by R. H. Richman and Y. C. Liu, Ford Motor Co.

The authors found that the deformation texture begins to change from the copper-type to a 70:30 type brass when approx 0.3 to 0.4 atom pct of P, As, and Sb were added to the copper. Concurrently, a new set of recrystallization components appear in the composition range where the deformation transition begins; the copper-type components diminish or disappear. The major new components have {110} planes in the plane of the sheet. The authors, when questioned, stated that there was no correlation between solubility of the solutes and change of the deformation textures. They also stated that the new recrystallization components were not the result of incomplete recrystallization.

Annealing Twins and Coincidence Site Boundaries in High-Purity Lead, by K. T. Aust and J. W. Rutter, General Electric Co.

The authors applied the Fullman-Fisher theory to the formation of annealing twins in zone-refined lead containing less than 1.4 atom ppm of Sn, Ag or Au. They observed that during growth of a recrystallized grain into a crystal containing low angle boundaries, twins of the growing grains would form, and grow into the higher-energy crystal. In every case of successful twin growth, a large-angle random grain boundary was replaced by a large-angle *coincidence type* boundary of the type proposed by Kronberg and Wilson. Repeated twinning led to boundaries having successively higher densities of coincidence sites. Since the twin boundaries were about 5 pct lower in energy than the *random* boundaries, twinning resulted in a decrease in the energy of the system.

Solidification

Reviewed by R. E. Boni, Armco Steel Corp.

Condensation Coefficients of Silver, Zinc, and Cadmium in Growth from the Vapor Phase, by R. A. Rapp, Max Planck Institut für Physicalische Chemie, J. P. Hirth, Carnegie Institute of Technology, and G. M. Pound, Sheffield University.

The authors obtained condensation coefficients of unity for cadmium, silver, and zinc deposited on the same solids. Wide temperature and pressure ranges were explored for silver; condensation coefficients less than unity reported by previous investigators were ascribed to impure substrates.

On the Structure of Single Crystals Grown from the Melt, by P. E. Doherty and R. S. Davis, Arthur D. Little, Inc.

The authors detected pits and pores in single crystals of aluminum grown from the melt. Pores were attributed to inadequate feeding of liquid during solidification or to gas evolution. No pits were found adjacent to pores.

Solute Segregation During Dendritic Growth, by F. Weinberg, Canadian Department of Mines and Technical Surveys.

The author utilized autoradiographic and decanting techniques to study solute segregation during dendritic growth. He found marked segregation in the following systems:

Th^{234} in Zn, Sn, and Pb; Ag^{110} in Pb and Zn; Zn^{65} in Pb and Sn; Sn^{119} in Pb; and Co^{60} in Pb.

No theory adequately explained these observations, since dendritic growth is assumed to be so rapid that diffusion is not a factor.

Development of Preferred Crystal Orientation in Cast Silicon-Iron Ingots, by H. J. Fisher and J. L. Walter, General Electric Co.

The authors prepared ingots of Fe—3.25 pct Si with cubic orientation, {100} {001}. Epitaxial growth occurred when superheated melts were poured on hearths consisting of columnar grains or laminated cube-on-edge sheets stacked at 45° to the mold wall. Heat was extracted unidirectionally through the hearth. Columnar growth progressed as long as a slight temperature gradient existed at the liquid-solid interface. Silicon decreased slightly within the columnar zone to a minimum at the columnar-equiaxed interface. Then, silicon rose 0.3 pct within the equiaxed zone.

Some Engineering Aspects of Metal Solidification, by M. C. Flemings and H. F. Taylor, Massachusetts Institute of Technology.

This paper described some recent work with slab-type sand castings with chilled ends. Microporosity and intergranular precipitation increased with distance away from the chill plate of slab-type sand castings. Directionality of heat extraction opened channels for the transport of fluid for feeding. From 30 to 40 pct reductions of area in 300,000 psi ultra-high strength steels were obtained where there was no microporosity.

Interface Temperature of Two Media in Poor Thermal Contact, by G. Horvay and R. H. Edsall, General Electric Co.

Utilization of the assumptions that the casting and mold are semi-infinitely thick . . . that the air gap occurs immediately . . . that a single freezing temperature exists . . . and that the metal is superheated enabled the authors to treat the heat flow problem that exists during cooling of a casting. The air gap was unimportant in sand casting but delayed freezing in iron molds. In the discussion, V. Paschkis objected to the assumption that the air gap exists from the beginning: time of air gap formation should effect total solidification time and ingot mold interface temperature, he stated.

Viscous Shear as an Agent for Grain Refinement in Cast Metal, by F. A. Crossley, A. G. Metcalfe, and R. D. Fisher, Armour Research Institute.

The authors refined the grains of small aluminum castings by magnetic stirring or mechanical rotation of the ingot. Grain refinement occurred only during the accelerational period of mechanical rotation. No effect was detected after the rotational velocity became constant. Viscous shear at the solidification front supposedly increased the number of atoms which passed the nuclei. During the discussion period, W. A. Tiller contended that viscous shear could not change the number of atoms in contact with the embryo. Severe turbulence would be necessary.

On the Growth of Germanium Dendrites by R. S. Wagner, Bell Telephone Laboratories.

Summarized by the author:

Billig reported on the growth of plate-like germanium dendrites with {111} faces by pulling from a seeded supercooled melt. Later Billig and Holmes reported that such dendrites contained a thin lamella bounded by twin planes parallel to the main faces of the dendrite. Recently, Bennett and Longini attempted to explain this dendritic growth by a mechanism involving a single twin plane. All the mechanisms proposed by these workers have serious shortcomings.

We have found, however, that growth of germanium crystals in contact with a supercooled melt can be either slow (polyhedral) or very rapid (dendritic) depending on the crystallographic nature of the seed crystal.

A mechanism is proposed for the dendritic growth process, which is based on the presence of at least two parallel coherent twin planes, and experimental confirmation is given.

The essence of the mechanism is that the two twin planes which bound the lamella produce in the sides of the growing dendrite a self-perpetuating system of *grooves* in which nucleation and growth occur readily. If only one, or no, twin plane is present, growth will be slow and polyhedral, not dendritic.

Propagation of Germanium Dendrites, by J. W. Faust, Jr., D. R. Hamilton, H. F. John, and R. G. Seidensticker, Westinghouse Research Laboratories.

Summarized by the authors:

The role of twin planes in the rapid dendritic propagation of germanium crystals is examined on the basis of easy corner growth. The essential argument involves the relative ease of nucleation in re-entrant corners, bounded by {111} faces, as opposed to nucleation on completed {111} faces.

A model is proposed which requires the presence of at least two twin planes to assure the perpetuation of a re-entrant corner. If only one twin plane is present, the germanium crystal is not capable of indefinite propagation, since growth in any corners initially present causes them to *grow out* and vanish. They are replaced by ridge structures where nucleation is difficult, a situation that cannot occur if more than one twin plane is present in the lattice. In this case, a growth layer, starting at a re-entrant corner at the first twin plane, grows up to the second

twin plane and there creates a new type of re-entrancy, one with an angle of 109½°. The ridge structure that was previously present has been replaced by a corner which is favorable to nucleation. Consequently, the requirement of nucleation about the adjacent ridge at the second twin plane has been removed. Thus, the crystal with two twin planes cannot be entirely bounded by slow growing ridges. The crystal with two twin planes is capable of indefinite propagation by corner nucleation in the six equivalent <211> directions. Since growth from one re-entrant corner supports nucleation in another, an interesting sort of *spiral* flow of growth steps can occur at the extreme tip of the growing dendrite. The spiral growth does not arise from any single screw dislocation, or even from a single network of screws, but rather from the unusual geometry of the interface.

Experimentally, it has been observed that at least two twin planes have been present in all samples of dendrites examined. Billig also mentions this. Furthermore, germanium dendrites with two twin planes exhibit six-fold growth symmetry. Thus, the mechanism discussed is in agreement with present experimental information. The presence of two twin planes in the germanium lattice is necessary to ensure indefinite easy propagation through corner nucleation.

The processes involved in the widening and thickening of dendrites, as opposed to their propagation, have been studied by means of metallographic techniques. Under certain conditions, resistivity variations and structural differences give small variations in etching rate. By studying etched cross-sections and {111} faces of germanium dendrites, it has been possible to deduce, in a fairly straightforward way, the progress of growth during the formation of a dendritic ribbon. These studies have revealed that the formation of such ribbons is a more complex process than had been suspected by earlier investigators. For example, it is found that the twinned structure is not involved in the widening of the dendrite. The twinned structure may become degenerate, or even discontinuous across the width of the dendrite. Some of the steps actually involved in the widening of a germanium dendrite bear a close resemblance to dendritic growth processes in metals, thus giving adequate justification for using the term, dendrite, when referring to ribbons of germanium as described by Billig and Bennett and Longini.

Powder Metallurgy—Dispersion Hardening and Strengthening

Reviewed by A. D. Schwope, Clevite Corp., and N. J. Grant, MIT.

Survey of Dispersion Strengthening in Metals and Alloys, by R. F. Bunshah and C. G. Goetzel, New York University.

This paper surveyed and systematized the present state of knowledge in the field of dispersion hardening. Although thoriated tungsten has been used for over 40 years, it remained for the sintered aluminum powders (SAP) to reawaken the interest in the strengthening of metals by discrete particles. As the authors pointed out, of the two methods to obtain dispersion—1) insoluble phases and 2) heat treating to gain a soluble second phase—the second method forms the basis of many present commercial high-strength, high-temperature alloys. The insoluble phase approach is subject of intensive investigation using powder metallurgical techniques. Among the variables increasing the dispersion hardening effectiveness are: particle spacing (0.01-0.1 μ), shape, low reactivity of particle with matrix, high hardness of dispersed phase, and stored energy.

Dispersion Hardening in the Copper-Alumina System, by K. M. Zwilsky, New England Materials Laboratory, and N. J. Grant, MIT.

The authors described the preparation and properties of copper strengthened with up to 10 vol pct of Al_2O_3. The alloys were prepared by mechanical mixing (a relatively simple technique) and resulted in alloys of high creep strength and extreme structural stability. The best alloy showed a stress for a 100-hr life at 450°C of about 25,000 psi, and resisted recrystallization at temperatures up to 1000°C.

Dispersion Hardening of Copper, by Oliver Preston, Stanford Research Institute and N. J. Grant, MIT.

Described were Cu-SiO_2 and Cu-Al_2O_3 alloys prepared by the internal oxidation of dilute solutions of Si or Al in Cu. Such structures show oxide particle sizes ranging from about 50 to 1000 Å radius, the finer particles being associated with the Cu-Al_2O_3 alloys, and the coarser ones with the Cu-SiO_2 alloys. The structures of these alloys are considerably more ideal than those of alloys prepared from mechanically-mixed powders, and result in strength properties significantly higher. A Cu-3.5 v/o Al_2O_3 alloy showed a stress for a 100-hr life at 450°C of 38,000 psi, and resisted recrystallization at 1050°C. A dispersion hardening model was suggested, based on the combined effects of a dispersed phase plus retention of stored energy from the extrusion step.

Effects of Stored Energy and Recrystallization on the Creep Rupture Properties of Internally Oxidized Copper-Alumina and Copper-Silica Alloys, by Masao Adachi and N. J. Grant, MIT.

The changes which occur in the properties of these internally-oxidized alloys after partial or complete recrystallization were discussed. The higher Al_2O_3 alloys were not completely recrystallized even after 20 hr at 1050°C, whereas the coarser oxide particle Cu-SiO_2 alloys recrystallized 100 pct after only a few hours at 1000°C. Of particular interest was the evidence that some of the strength could be recovered in the recrystallized alloys by coldworking again at room temperature.

Dispersion Hardening, by W. H. Meiklejohn and R. E. Skoda, General Electric Co.

The paper described iron-mercury alloys prepared in a unique way to produce insoluble particles of 50 to 1000 Å of iron in mercury. These structures were utilized to develop a relationship between the increase in yield strength and the structure. The authors conclude that the increase in yield strength depends only on the volume fraction of dispersed phase—somewhat in disagreement with some of the other theories which have been presented for these structures.

Influence of Processing Variables on the Properties of Nickel-Aluminum Oxide Alloys, by L. J. Bonis and N. J. Grant, MIT.

The authors, using Ni-Al_2O_3 alloys prepared by mechanical mixing of individual powders, studied

processing variables as a factor in the reproducibility of properties and in the magnitude of the properties. They showed that these Ni-Al_2O_3 alloys show strength values superior to the best commercial nickel base age-hardened alloys at temperatures of about 1000°C and higher.

Effect of Dispersion on the Ductile-Brittle Transition of Silver Chloride, by T. L. Johnston, R. J. Stokes, and C. H. Li, Minneapolis-Honeywell Regulator Co.

The authors studied the ductile-to-brittle transition temperature of silver chloride containing a finely-dispersed Al_2O_3 structure. Especially interesting was the evidence that the presence of finely-dispersed Al_2O_3 induced fibrous cracking and thereby increased the energy absorbed during crack propagation. The temperature for the ductile to brittle transition temperature was decreased by this dispersion.

Surface Phenomena for Mineral, Ceramic, and Metallurgical Systems

Reviewed by J. L. Walter, General Electric Research Laboratory.

Elementary Concepts of Surface Energy and their Applications in the Metallurgical Industry, by C. S. Smith, University of Chicago.

The author stressed the geometrical aspects of inter-atomic forces; unsymmetrically bound atoms at interfaces have a higher energy than the atoms at some distance from the interface. The geometry of interfaces in bubble systems was related to grain growth in metal and ceramic systems. Unused bonds of atoms at a grain boundary determine the grain boundary energy—the greater the angle of deviation between grains, the greater the number of unused bonds.

The Influence of Solutes on Interfacial Tensions and on the Contact Angle, by J. Th. G. Overbeek, University of Southern California and P. L. de Bruyn, MIT.

This paper showed that wetting occurs if a solute 1) decreases the interfacial tension between the liquid and the gas, or, 2) if it increases the solid-gas interfacial tension. Dewetting, on the other hand, requires that the solute be adsorbed at the solid-gas interface to decrease the tension between the solid and the gas. These principles were applied to flotation in which the collector is either chemically or electrically attached to one solid rather than to another one.

Kinetics of Wetting and Surface Energies of Solid Metals, by C. M. Adams, MIT.

The author applied thermodynamic considerations of equilibria to the wetting of a solid by a liquid and considered the cases of capillary flow and liquid spreading on a solid metal surface. Spreading occurs if the interfacial energy between the solid and the liquid metal is low compared to the liquid-vapor or the solid-vapor interfaces. Equipment was described, as well as some experimental results in which contact angles of liquid metals on copper plates were measured. The experimental results suggest that oxygen at the solid surface promotes wetting of the surface. The possibility that the liquid-gas interface possessed a mechanical strength which would retard spreading of the upper layers of the liquid thereby changing the contact angles was also discussed.

Some Aspects of the Foaming of Fused Silicates, by C. F. Cooper and C. L. McCabe, Carnegie Institute of Technology.

Discussed were the effects of additions of acidic oxides and basic oxides on the stability of the foams of acid silicate melts. Additions of Fe_2O_3 and Cr_2O_3 caused stability whereas the basic oxides did not. The observation that acid oxides stabilize foams was discussed in terms of the surface tensions of the oxides added and their ability to form networks.

Crystal Growth in Solids, by D. Turnbull, General Electric Co.

In this paper the authors discussed the effects of impurity particles and solid solution impurities on the migration of grain boundaries. The recent work of Aust and Rutter was included to show that anomalously high activation energies for migration of grain boundaries were related to the presence of impurity atoms at the boundaries. In pure materials, the activation energy for migration is close to the activation energy for vacancy diffusion. It was also pointed out that segregation of sulfur at grain boundaries in iron-silicon alloys may produce a dislocation network near the boundaries. Impurities adsorbed at the network may act to retard boundary migration.

Surface Chemistry and the Kinetics of Sintering Processes, by W. D. Kingery, MIT.

Sintering of powdered compacts was discussed in terms of a decrease in surface energy—corresponding to the lower surface area of the sintered product. Both single-and multi-phase systems were discussed. In multi-phase systems, the liquid phase penetrates between the solid grains; the driving force for grain growth then is the decrease in the liquid-solid interfacial energy. Complete wetting of the solid particles by the liquid must occur if rates of densification are to be increased by the addition of a liquid phase.

Geometric Equilibria and Nonmetallic Microstructures, by L. H. Van Vlack, University of Michigan.

The paper described the role of geometric equilibria in developing microstructures in nonmetallics. The interphase boundary energy is reduced by 1) grain growth and 2) rounding of grain corners (anhedralization). The structure therefore depends on the boundary-free energy. These geometrical considerations were applied to formation of nonmetallic inclusions in steel, to the strength of refractory bricks, and to penetration of molten iron into sand molds.

Graphite Formation and Surface Tension in Cast Iron, by J. Keverian, General Electric Co.

Measurements of surface tension and contact angles of carbon-saturated iron alloys on a graphite plate were reported. Sulfur was found to reduce the surface tension of the iron-carbon melts and may also be preferentially adsorbed at the graphite-melt interface. Graphite-spherodizing elements serve to scavenge the sulfur, increasing the interfacial energy between the liquid and the graphite. Microstructures of the alloys and theories of graphite formation were discussed.

SHORT-TIME, RAPID-HEATING, ELEVATED TEMPERATURE TESTING

by Robert E. Mihalco of Convair Div., General Dynamics Corp.

Today, the aircraft industry is faced with a serious materials problem which threatens to be a limiting factor in man's future aeronautical accomplishments. This problem can be solved by the development of new materials, and more important, by more efficient use of those we have.

The field of short-time, rapid-heating, elevated-temperature testing is already beginning to play a leading role in the efforts to increase the efficiency of materials. In missiles, supersonic aircraft, and space vehicles, very high rates of heating usually occur for a few seconds but rarely for more than a few minutes. Attempts to extrapolate conventional long-time, elevated-temperature, creep and tensile data are futile because our fundamental knowledge of materials behavior is inadequate. Therefore, it becomes necessary to develop methods of testing which would duplicate the environments to which a material would be exposed during its mission. These new test methods would have to provide positive control over the following variables: 1) rate of heating, 2) temperature, 3) loading rate, and 4) strain rate. In addition, methods for accurate data recording would be required.

Testing methods

At least four methods of achieving controlled rapid heating rates are possible: resistance heating, hot-fluid heating, radiant heating, and induction heating. Resistance heating is accomplished by passing a high-amperage, low-voltage, alternating or direct current through the specimen. Heating rates can be controlled by varying the amount of current passing through the specimen. Upon reaching the desired temperature, the current is reduced to a value sufficient to maintain the setting. Because of its simplicity, versatility, and ease of control, resistance-type heating is preferred by most companies.

Hot fluid heating has been employed by Convair/Pomona, Convair Div. of General Dynamics Corp., to simulate aerodynamic heating. This method consists of heating a fluid to the desired test temperature and then pumping hot fluid past the immersed test specimen. The velocity of the fluid determines the heating rate. Advantages of this system are accurate temperature control without over-shoot, and true aerodynamic heating simulation. The upper limit to hot fluid heating is about 1200°F. Above this temperature, mechanical problems of immersing the test fixtures in molten fluids become critical.

Radiant heating methods using quartz lamps, metal strips, etc., have been used for specific type tests. However, this type of heating, up to now, has been rather specialized. Induction heating is being investigated but the work done to date is not sufficient to determine the merits of this test method.

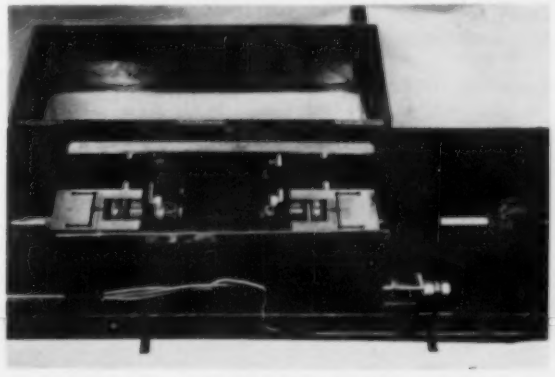


Fig. 1—Left, laboratory layout, including temperature controller and power regulator, test unit, and load-strain, load-time, strain-time recorders. Fig. 2—Right, close-up view of the test unit.

Testing variables

Temperature is perhaps the easiest variable to control. Up to 3000°F thermocouples are almost universally used. Above 3000°F, radiation pyrometers or (in special cases) nonstandard thermocouples would be used to measure temperature. The biggest problem is utilizing thermocouples to their greatest advantage; this necessitates proper selection of thermocouple type, size, and instrumentation to assure accuracy, sensitivity, and response. In general, thermocouples are attached to the specimen by welding. Care must be taken to maintain calibration and correction factors of spot-welded thermocouples.

Loads can be applied by dead weight, mechanical systems, or hydraulic systems. Dead-weight loading is the simplest and least expensive but also is very restricted in its uses. Mechanical systems are lacking in versatility and have problems with friction, response, and inertia. Hydraulic systems are the most desirable and in general the most widely used. Hydraulic loading systems can provide infinite adjustment, rapid response, and close control.

Generally, the use of an extensometer is the only method of strain measurement accurate enough to obtain reliable properties. Either strain gages or variable linear differential transformers can be used to make an extensometer. Since the specimen will be at temperature, care must be taken to insure proper insulation and protection from heating. Precautions must be taken to assure positive contact between the extensometer and the specimen to assure accurate strain measurements.

Data recording is the culmination of the entire effort of performing elevated temperature tests under controlled conditions. The most closely controlled tests possible are worthless without records of what happened during the test. It is, therefore, necessary to integrate a recording system which can make permanent records of load-strain, load-time, strain-time, and temperature. It is also important that these recording instruments have a response greater than the rate of change in the variables being recorded.

Resistance-heated unit

Convair/Pomona, Convair Div. of General Dynamics Corp., has recently completed and put into operation a resistance-heated, elevated-temperature testing unit capable of testing materials to 3000°F. With this equipment, heating rates can be controlled up to 500°F per sec; strain rates can be electronically controlled from 0.00005 to 0.1 in. per in. per sec; and loading rates can be controlled from a static load condition up to and including specimen rupture in ¼ sec. The test area can be enclosed to enable testing in inert atmosphere. The use of an optical pyrometer extends the test range to 4000°F.

A more detailed discussion of the resistance-heated, high-temperature unit can best be made by breaking the unit into its component parts and discussing each individually. Fig. 1 is a photograph of the entire testing layout, including the temperature controller and power regulator . . . the test unit . . . and the load-strain, load-time, strain-time recorders.

Fig. 2 is a close-up of the test unit. The geometry of the specimen is quite simple, consisting of a 0.500 in. wide and 12 in. long strip of material with parallel sides. Specimen thicknesses varying from 0.020 to 0.100 in. can be tested. Convair developed the unique set of grips which made possible the use of this type test specimen. The advantages of such a specimen are, obviously, low material and machining costs. The specimen is horizontal to eliminate the *chimney* heating effect, and the length of the coupon assures temperature uniformity across the 2 in. gage length.

The grips are designed for loads up to 10,000 lb and are capable of withstanding a 40 pct overload. Power is fed through leads into the grips which are electrically insulated from the hydraulic loading mechanism and rigid test stand. The extensometer is a light-weight, carbide-tipped, strain-measuring instrument designed by Convair. It consists of linear variable differential transformers which sense the strain over the 2-in. gage length. Counter balanced extension arms transmit the strain to the differential transformers below the specimen to eliminate the effect of heat from the coupon.

Thermocouple attachment is made by spotwelding appropriate thermocouple combinations directly to the coupon. Connections are available for as many as five separate thermocouples for temperature measurement and control on the specimen.

Loading is applied through a servo-controlled hydraulic unit. The load is measured with a ring dynamometer. Various combinations of load dynamometers and hydraulic cylinders are available to increase the accuracy of testing by selecting the units with the highest response for a particular set of conditions.

A Research Inc. temperature controller and power regulator is used to control and program temperatures. This unit is a complete three-phase ignitron power control unit in combination with three direct current potentiometric circuits and high gain amplifiers. With this unit, heating rates, soaking times, or any time-temperature combination desired can be programmed and automatically controlled.

Strain is sensed by the extensometer and converted into an electrical signal through the linear variable differential transformers. This differentiated position signal is hooked into a feedback system which controls the servo valve of the hydraulic system. With this closed loop feedback system, it is possible to program the desired strain rate of any particular test from 0.00005 to 0.1 in. per in. per sec.

The load measuring system is also a closed loop servo-controlled feedback system. Loads can be programmed and controlled much the same as strain. With the high response servo valve, loads can be applied in ¼ sec and maintained within ± 1 pct of the desired value throughout a test.

For each test run, a complete load-strain curve is automatically recorded from which the mechanical properties can be obtained. These include ultimate tensile strength, yield strength, and modulus. In addition, records are made of the load-time, and strain-time conditions throughout the test. Due to the overheating of a resistance-heated specimen when necking down, elongation values generally are not reported. Tensile creep testing also can be performed with the recording of the necessary data.

With this equipment, short-time, rapid-heating rate, elevated-temperature properties of annealed and cold worked alloys of columbium, tantalum, and tungsten have been obtained successfully up to 3000°F. Additional testing of other developmental refractory metals under the same type conditions is continuing.

Summary

For the past eight years, Convair/Pomona has developed and used test methods which simulate flight environments. The latest and most versatile test unit has recently been completed and is now in operation. This new unit is capable of testing under closely controlled and programmed heating rates, strain rates, and loading rates.

We find that material efficiency can be improved considerably provided comprehensive material data is obtained using test methods capable of simulating flight environments. Test data obtained under these controlled conditions increases the efficiency of a material considerably by reducing *safety factors* (perhaps more properly called *ignorance factors*) which designers use to obtain reliability. With these test methods, the efficiency of both new and presently available materials can be improved considerably, thereby aiding in the solution of our present day materials problem.

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NEWS OF YOUR PROFESSION

ISD Portion of Fall Meeting to Include 8 Papers

The Iron and Steel Division has scheduled two sessions for the Fall Meeting of The Metallurgical Society in Philadelphia. Titles of papers and authors follow:

Predicting Effects of Oxygen, Moisture, and Fuel Additions on Blast Furnace Operations With a Computer by A. L. Hodge, Linde Co.

Correlation Analysis of Roof Lance Operations in An Open Hearth Furnace by A. P. Woods, Armco Steel Corp.

A Simulation of Melt Shop Operation Using A Computer by R. Neate and W. J. Dacey, Steel Co. of Wales, Ltd.

Technology of Dwight-Lloyd McWane Process for Making Iron by T. E. Ban and B. W. Worthington, McDowell Co., Inc.

The Kinetics of the Iron Oxide Reduction Steps by A. Wilhelm and G. St. Pierre, Ohio State University.

Sulfide Inclusions in Steel by L. VanVlack, D. Riegger, R. Warrick, and J. Dahl, University of Michigan.

Phase Equilibrium Studies of Synthetic Nonmetallic Inclusions in the FeO-MnO-MnS-SiO_2 System by E. H. Silverman, U.S. Steel Corp.

Effect of Chromium on the Activity of Sulfur in Liquid Iron by N. R. Griffing and G. W. Healy, Union Carbide Metals Co.

Phase Transformations in Melbourne Meeting

A symposium on Phase Transformations in Metals and Alloys will be held at the University of Melbourne Engineering School Nov. 10-11. Thirteen papers will be presented; they appear in the August issue of the *Journal of the Australian Institute of Metals*. The symposium is being sponsored by the Physical Metallurgy Division, Melbourne Branch, Australian Institute of Metals.

For more information, contact: I. J. Polmear, The Chief Superintendent, Aeronautical Research Laboratories, c/o Box 4331, G.P.O., Melbourne, Australia.

Unable to accept his certificate of Honorary Membership at this year's Annual Meeting, William E. Wrather was visited by AIME President, Joseph L. Gillson, at his Washington, D. C. home. Prior to his wheelchair incapacitation, Dr. Wrather was Director of the US Geological Survey.

New *TRANSACTIONS* Policy Instituted

A new policy will go into effect in October regarding reprinting of TRANSACTIONS papers. Beginning then they will become *preprints*, not *reprints*. In the past, reprinting of papers which appeared in TRANSACTIONS meant a time lag of two months after publication.

Now, it is anticipated that preprints will be mailed about 30 days prior to publication. To adhere to this preprint system, it has been necessary to establish a uniform preprint schedule. A study has revealed that 200 preprints should adequately fulfill the demands of most authors. There will be no complimentary copies. For those authors desiring additional copies of their work, reprints can be ordered in the established manner and will be received about two months after publication.

To pay for this preprint system, the Board of Directors of The Metallurgical Society has decided to institute a charge for the 200 preprints based on a 20-pct discount of the current reprint charge schedule. The success of the program will depend upon the majority of authors accepting the purchase of 200 preprints of their paper.

Reserve IMD Sessions for Fall Meeting

The June 29th deadline for submission of abstracts to Institute of Metals Division-sponsored sessions during the Fall Meeting brought forth a bevy of response. At this writing, the following sessions have been reserved for the indicated committees:

Chemistry and Physics of Metals—four sessions, two of invited papers and two of contributed papers. One of each type of session will be devoted to 1) Diffusion in Magnetic Materials; and 2) The Effect of Extremely High Pressures.

Ferrous Metallurgy—whole-day symposium on The Decomposition of Austenite by Diffusional Processes. The focus will be on fundamental, rather than technological, aspects of austenite decomposition. Special attention will be given pearlite, bainite, ferrite, and cementite reactions.

Melting and Casting—whole-day symposium on Ingot Structure Control; six papers.

Nuclear Metallurgy—whole-day symposium on Metallic Moderators and Cladding Materials; 14 papers scheduled.

Refractory Metals—two sessions, one on Department of Defense Refractory Metal Sheet Program; and the second on European Activities and Developments in Refractory Metals.

Shaping and Forming—half-day meeting consisting of three papers on Engineering Fundamentals of the Rolling Process.

Structural Materials—half-day session on Structural Materials in Cryogenic Design; six papers scheduled.

Titanium—half-day session on Titanium vs Steel and Aluminum in Pressure Vessels for Hydrospace, Aerospace, and Space; four papers are tentatively scheduled.

Titles, authors, and abstracts of these papers will be published in the September issue, as will the Extractive Metallurgy Division and Iron and Steel Division contributions to the program.

Metallurgy Of Elemental And Compound Semiconductors

STATLER HOTEL, BOSTON, AUGUST 29-31

Sponsored by

Semiconductors Committee, Institute of Metals
Division of The Metallurgical Society, and
Boston Section, AIME

SUNDAY, AUGUST 28

Registration, Mezzanine, Statler Hotel
Registration in Parlors A and B
9:00 am to 5:00 pm Monday and Tuesday

MONDAY, AUGUST 29

Esaki-Tunnel Diodes

9:15 am to 12:30 pm — Georgian Room

M. Tanenbaum, Bell Telephone Labs., presiding.

Opening Remarks—D. C. Jillson, Chairman, Semiconductors Committee.

Materials Requirements for Esaki-Tunnel Diodes:
G. C. Dacey, Bell Telephone Labs.

Heavily Doped Materials for Esaki-Tunnel Diodes:
F. A. Trumbore, Bell Telephone Labs.

Quantitative Aspects of Doping in a Magnetic Crystal Puller:
H. T. Minden, General Telephone and Electronics Labs, Inc.

Impurity Doping for Silicon Tunnel Diodes:
L. V. Lunn, C. T. Sah, and C. S. Roberts, Fairchild Semiconductor Corp.

Growth and Properties of Heavily Doped Germanium Single Crystals:
J. R. Patel, R. F. Tramposch, and A. R. Chaudhuri, Raytheon Co.

Esaki-Tunnel Diodes

2:00 pm to 5:00 pm — Georgian Room

K. Weiser, International Business Machine Corp., presiding.

Growth of Gallium Arsenide Crystals from Dilute Solutions:
L. J. Vieland and S. Skalski, Radio Corp. of America.

Hall Measurements on Tunnel Diode Materials:
T. E. Seidel, Radio Corp. of America.

Preparation of Esaki Diodes from Dendritic Material:
T. P. Brodie and J. P. McKelvey, Westinghouse Electric Corp.

Solid Solutions of III-V Compounds in Germanium:
J. O. McCaldin, Hughes Aircraft Corp.

Formation of Cubic Silicon Carbide in Silicon Solutions:
A. H. Smith, Raytheon Co.

Growth of III-V Compounds and Alloys from Solution:
E. P. Stambaugh, J. F. Miller, and R. C. Himes, Battelle Memorial Institute.

Silicon, Arsenic, Whiskers, and Tunnel Diodes:
N. Holonyak, Jr., D. C. Jillson, I. A. Lesk, and A. I Bevacqua, General Electric Co.

6:00 pm Cocktails and Dinner, Georgian Room

TUESDAY, AUGUST 30

Dendritic Growth

9:00 am to 12:30 pm — Georgian Room

L. Pensak, Radio Corp. of America, presiding.

Fundamentals of Dendritic Growth:
W. A. Tiller, Westinghouse Electric Corp.

Controlled Dendritic Growth of Materials with Zinc-Blende Structures:
H. F. John, Westinghouse Electric Corp.

Dendritic Growth of Semiconductors:
P. J. Holmes, Associated Electric Industries, Ltd., Aldermaston, Berkshire, England.

Solute Segregation in Dendrites of Semiconductors:
S. O'Hara, Westinghouse Electric Corp.

Continuous Growth of Germanium Dendrites:
W. J. Smith, Westinghouse Electric Corp.

Factors Influencing Dendritic Growth in Germanium:
R. S. Wagner, Bell Telephone Labs.

Some Properties of Dendritic Ribbon Crystals of Germanium:
D. C. Jillson and R. E. Hysell, General Electric Co.

Vapor Growth

2:00 pm to 5:00 pm — Georgian Room

V. Ozarow, General Electric Co., presiding.

Epitaxial Growth of Silicon P-N Layers from the Vapor Phase:
E. S. Wajda, International Business Machines Corp.

Silicon P-N Junctions for Device Applications by Direct Deposition from a Vapor Phase:
J. E. Allegretti and D. J. Shoambert, Merck and Co. Inc.

Epitaxial Vapor-Growth and Doping of Germanium by a Closed-Cycle Germanium-Iodine Reaction:
J. C. Marinace, W. E. Baker, and D. M. J. Compton, International Business Machines Corp.

Growth Forms and Dislocation Content of Iodide-Grown Germanium Crystals:
H. S. Ingham, Jr., P. J. McDade, and D. M. J. Compton, International Business Machines Corp.

Growth of Cubic Silicon Carbide Single Crystals by Gaseous Cracking:
R. C. Ellis, Jr., Raytheon Co.

Preparation of Semiconductor Films from Metal-Organic Vapors:
E. H. Tompkins, A. C. Claus, and B. C. Harrison, Armour Research Foundation.

WEDNESDAY, AUGUST 31

Growth of Other Materials

9:00 am to 12:30 pm — Parlors A, B, and C

J. W. Ross, Texas Instruments, Inc., presiding

Preparation of High-Purity Boron and Crystal Growth by a Crucible-Free Technique:
W. E. Medcalf, K. E. Bean and R. J. Starks, Eagle-Picher Co.

Use of Surface Tension in Pulling Single Crystals of Controlled Dimensions:
G. K. Gaule and J. R. Pastore, U. S. Army Signal Research and Development Lab.

Differential Charge Compensation in Heavily Zinc-Doped GaP-Si Alloys:
E. E. Loebner, I. J. Hegyi, and E. W. Poor, Jr., Radio Corp. of America.

Preparation and Physical Properties of Crystals in the HgTe-CdTe Solid Solution Series:
J. Blair and R. Newnham, Massachusetts Institute of Technology.

X-Ray Investigation of the Perfection of Silicon:
J. R. Patel, R. S. Wagner, and S. Moss, Raytheon Co.

Behavior of Certain Thermoelectric Materials in Nuclear Reactor Environments:
M. Balicki, R. T. Frost and J. C. Corelli, General Electric Co.

Preparation of Single Crystals of Bi_2Te_3 by the Czochralski Method:
Jane Dennis, O. P. Manley, F. Shepherd, and A. Yang, Massachusetts Institute of Technology and Air Force Research Center.

Impurities in III-V Compounds and Mutual Solubility of III-V Compounds, K. Weiser, International Business Machines Corp.

Registration

Advance registration material has been sent to most persons reading this announcement. If interested, contact *H. E. Bridgers, Bell Telephone Labs., 555 Union Blvd., Allentown, Pa.* Registration fee for the Conference, including the Proceedings Volume, is $10 for AIME members; $15 for non-members. Non-members who submit applications for membership prior to or upon registering are eligible for the member rate of $10. Refunds of $5 will be made to non-members joining during the Conference.

Proceedings Volume

The papers and discussions at the Conference will be published as one of the continuing series of METALLURGICAL SOCIETY CONFERENCES, printed by Interscience Publishers, Inc. The volume will be automatically sent registrants without further charge. Every effort will be made to insure prompt publication of the volume so as to increase its usefulness to registrants.

PLAIN FACTS ABOUT THE SOCIETY

1 The Metallurgical Society of AIME is continually planning a program of more and better services for all its members.

2 This program requires substantial membership growth, since the cost of providing services to each member decreases with increased membership.

3 There is a known potential for such an increase among all types of Metals Men now served by the Society through its various Divisions.

4 A great number of qualified persons have not joined The Metallurgical Society simply because they have never been invited to do so.

Conclusion: YOU will benefit from the program to increase and improve services, but only if YOU are personally active in the drive to obtain new members. No new members, no new services; its as simple as that.

Action Required: Ask at least one nonmember colleague to join The Metallurgical Society within the next 30 days. If unable to make a personal contact, use the form on last page to propose a qualified Metals Man for membership.

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THE METALLURGICAL SOCIETY OF AIME
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AROUND THE SECTIONS

Colorado section drew the largest attendance of the year on May 19th when 69 members and guests convened at the Petroleum Club in Denver. Harry L. McNeill, vice president of Stearn-Roger Manufacturing Co., spoke on the Southern Peru Copper Corp.'s *Toquepala Project*.

The Section's next meeting will be in September.

Detroit section, NOHC, met at the Ford Motor Co.'s Central Office Building on June 22nd. George A. Ferris, manager, open hearth & electric furnaces, of the Co.'s Steel div., spoke on *Potential of the Open Hearth*. The talk was patterned on Ford's recent announcement (July, JOURNAL OF METALS, p. 511) about using oxygen to increase open-hearth production.

The meeting also was the occasion for election of 1960-1961 officers. Elected were Ralph Duffet, Chairman; George Ferris, Vice-Chairman; Bruce Ramage, Secretary; and John Brown, Treasurer.

Washington, D. C., section members visited Kennecott Refining Corp.'s new refinery outside Baltimore on June 7th. See story about refinery, pp. 470-471, June issue). Following the plant tour, Section members were luncheon guests of the Kennecott Refining Corp.

The Section's next meeting will be Tuesday, Oct. 4th.

G. H. Clamer Honored by Brass & Bronze Men on 85th Birthday

Guilliam H. Clamer—often called Mr. Brass and Bronze—was honored by The Brass and Bronze Ingot Institute recently on the ocassion of his 85th birthday. The party at the Ambassador Hotel in Chicago was highlighted by presentation of a scroll recognizing Dr. Clamer's 65 years of service to the nonferrous metals industry.

At the age of 22, Dr. Clamer founded the first laboratory in the nonferrous metals industry for Ajax Metal Co., and he has been engaged in research and development ever since. The most famous of his many inventions was the high-frequency induction furnace, developed with Dr. Edwin Northrup in 1918. The furnace became the basis of an industrial complex of fire corporations under the Ajax Electro Thermic Corp., a firm which he has headed since 1920. Dr. Clamer has been an AIME member since 1913.

Guilliam H. Clamer (left) is presented a testimonial scroll by Benjamin Harris, president of Benjamin Harris & Co., representing the Brass & Bronze Ingot Institute.

Penn State to Host Anthracite Meeting

The technical and scientific aspects of anthracite utilization will come under discussion during an Anthracite Conference on the Pennsylvania State University campus Nov. 15-16.

The final program is now complete, and includes papers on the use of anthracite in the production of briquettes, activated carbon, high-density coke, metallurgical coke, and ore sinters.

Persons seeking additional information should contact: P. L. Walker, Jr., Mineral Technology Division, Pennsylvania State University, University Park, Pa.

Gray Iron Meeting at Cincinatti Oct. 12-14

The Gray Iron Founders' Society will hold its 32nd Annual Meeting at the Netherlands Hilton Hotel, Cincinnati, Oct. 12-14. An appraisal of both problems and opportunities in the gray iron castings industry is the theme of the two-day meeting.

For more details, contact: W. M. Caldwell, Asst. Secretary, Gray Iron Founders' Society, Inc., National City-E, 6th Bldg., Cleveland 14, Ohio.

Papers, Panel, Play Are Ingredients for Rocky Mt. Meeting

When technical sessions begin at the Rocky Mountain Minerals Conference, abstracts of all papers will be available. Some of particular significance for metallurgists include the *Role of Micro-organisms in Leaching Processes* by an unnamed member of the Kennecott Research Center staff; *The Silverton Project of Standard Metals Corp.* by Russell L. Wood, asst. general manager of the firm; and *The Vernal Phosphate Project of San Francisco Chemical Co.* by D. L. King, general manager of the company. Papers also are forthcoming on the design of reagent systems and fused electrolysis, plus one on cost factors in the choice of nuclear fuels vs other fuels in the utilities industries.

The Conference will run Wednesday through Friday, Oct. 5-7, at the Newhouse Hotel in Salt Lake City.

On the morning of the final day a star-studded panel will take up the subject of exploration in Canada and the US—ore search objectives, development of mines from ore search to production, costs of ore search, and so on. On the panel will be Frances Cammeron, president, St. Joseph Lead Co.; C. P. Pollock, exploration manager, American Smelting & Refining Co.; Charles C. Huston, president, C. C. Huston & Associates, Toronto, Canada; and a fourth person to be named.

Besides technical sessions, there will be a full round of social activities, including breakfasts, luncheons, cocktail hours, and a dinner-dance. The ladies are not to be denied either, for a special luncheon and fashion show is on their agenda. Of course, they also may take in the field trip to the Hercules Powder Co. at Bacchus, Utah. Visitors will observe the making and testing of rocket motors and propellant fuels, production of nitroglycerine, and the making of normal explosives used primarily in the mining industry.

Diffraction Meeting at Pittsburgh Nov. 9-11

The annual Pittsburgh Diffraction Conference will be held Nov. 9-11 at Mellon Institute. Sessions will be devoted to metals and alloys, instrumentation, structures, polymers and fibers, refractories, electron probe, and electron diffraction. Scheduled to address the meeting is Professor I. Fankuchen, Polytechnic Institute of Brooklyn.

For more information, contact: L. F. Vassamillet, Mellon Institute, 4400 Fifth Ave., Pittsburgh 13, Pa.

MEMBERSHIP

Proposed for Membership
Metallurgical Society of AIME

Total AIME members on June 30, 1960, was 33,544; in addition 2,511 Student Members were enrolled.

ADMISSIONS COMMITTEE

L. L. Seigle, Chairman; W. L. Brytczuk; F. B. Foley; T. D. Jones; Harold Margolin; Shadburn Marshall.

The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who are unqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

Members

Azaroff, Leonid V., Chicago, Ill.
Brush, Edwin G., Alpaus, N. Y.
Cowperwaite, Irving A., Boston, Mass.
Etsuo, Hayashi, Troy, N. Y.
Fischer, Walter H., Detroit, Mich.
Gentile, Anthony J., Bristol, Conn.
Hornke, Glen R., Dearborn, Mich.
Irani, Dinsha K., Pittsburgh, Pa.
Johnson, Herbert G., Havertown, Pa.
Landucci, Louis P., Trail, B.C., Canada
Matsushima, Tomoo, Toronto, Ont., Canada
Mikaelian, Zaven, New Bedford, Mass.
Mikulski, Joseph F., Waterbury, Conn.
Patlogar, Henry W., Pueblo, Colo.
Peters, John T., Pittsburgh, Pa.
Pierce, Jack F., Blackwell, Okla.
Rea, James E., Pittsburgh, Pa.
Spencer, Donald B., Portland, Ore.
Stirling, Harold T., Pittsburgh, Pa.
Voice, Ernest W., London, England

Associate Members

Kuhl, Richard J., Chicago, Ill.
Roman Mata, Jose T., Mexico, Mexico
Reighart, James H., Cleveland, Ohio
Walsh, Edward J., Cleveland, Ohio
Whetstone, Richard D., New York, N. Y.
White, James J., Pittsburgh, Pa.

Junior Members

Crosby, Robert L., Rolla, Mo.
Donaldson, Alan D., Harvard, Mass.
Gravis, Lewis F., Gary, Ind.
Jackson, Charles R., Hammond, Ind.
Mohanty, Ganesh P., Chicago, Ill.
Patterson, Philip W., Pittsburgh, Pa.

REINSTATEMENT—MEMBER

Smith, Andrew P., Bethlehem, Pa.

REINSTATEMENT—JUNIOR MEMBER

Guyard, Robert L., Paris, France
Roy, Prodyot, Berkeley, Calif.

CHANGE OF STATUS

Associate to Member

Pallotta, Arnaldo, Sao Paulo, Brazil

SPECIAL REINSTATEMENT—STUDENTS

Colorado School of Mines
Crabtree, Edwin H., III

Royal School of Mines
Scarratt, Trevor

STUDENT MEMBERS

Illinois Institute of Technology
Rath, Bhakta B.

University of Kentucky
Steedly, James E., Jr.

Missouri School of Mines & Metallurgy
Becker, Charles P., Jr.
Catron, Jerry E.

University of Oregon
Beeson, Melvin H.
Thomson, George R.

South Dak. School of Mines & Tech.
Daughenbaugh, Gerald A.

NECROLOGY

Date Elected	Name	Date of Death
1933	Fox, Fred	May 30, 1960
1936	Franklin, R. E.	May 1, 1960
1949	Kimler, C. W.	March 19, 1960
1938	McDonald, J. C.	May 1, 1960
1959	Morek, A. W.	Unknown
1919	O'Connor, E. S.	May 25, 1960
1919	Sackett, B. L.	April 27, 1960
1954	Schranz, H. W.	April 26, 1960
1929	Shannon, P. F.	May 7, 1960
1925	Smith, E. C.	May 20, 1960

EARLE C. SMITH

An Appreciation

by Charles W. White

Smith is a common name. But when you add Earle C. in front of it, you have the name of an uncommon man.

The late Earle C. Smith, widely known and deeply respected chief metallurgist and director of research for Republic Steel Corp., had an uncommonly close working and personal relationship with steelmen of all rank from all over the world. Furthermore, he had the uncommon ability to talk and to listen, to understand and be understood, by people in all walks of life.

Mr. Smith was intensely loyal to his friends and they returned his loyalty. Because of his ability to inspire people to greater effort, there are a number of men in responsible positions today, not only in the steel industry but in numerous other fields, who benefited from Mr. Smith's counsel.

He was patient, yet had a restless desire to get a job done. He was tolerant, but couldn't stand mediocrity. He could plan for tomorrow, without losing sight of today.

His honor-studded career spanned almost half a century. He was born on January 20, 1891 in New Brighton, Pa., and was graduated from Ohio State University in 1913 as a mining engineer. He immediately went to work in the open hearths and rolling mills at Gary, Ind. He later returned to Ohio State to teach metallography for several years. During World War I, he was affiliated with the US Army Signal Corps in a civilian capacity, working with special steels for the aircraft industry.

Following the war, he became chief inspector for Central Steel Co., a predecessor company of Republic, in Massillon, Ohio. After a number of other assignments, he was appointed chief metallurgist for Republic in 1932 and, in 1956, also was made director of research.

Mr. Smith was chairman of the ferrous panel of the National Academy of Science's National Research Council, and a member of the National Bureau of Standards' Metallurgical Advisory Committee. He served on the Super Alloys Technical Industry Advisory Committee and the Stainless Steel Technical Industry Advisory Committee of the War Production Board, during World War II.

His many outstanding contributions to the AIME included the Howe Memorial Lecture in 1935, chairman of the Iron and Steel Division in 1942, and chairman of the Fairless Award Committee in 1959.

In 1940 he was awarded the American Iron and Steel Institute Medal. In 1946 he received the Gold Medal Award of the American Society for Metals. He was selected to give the AISI Charles M. Schwab Memorial Lecture in 1960. The paper he prepared was presented posthumously.

He received two honorary doctor's degrees and honorary memberships in the American Society for Metals and the Verein Deutscher Eisenhüttenleute.

Aside from the many tangible honors bestowed upon Mr. Smith, probably the greatest tribute to him is the many friendships he enjoyed throughout the world—friendships which represented a true cross-section of mankind.

Earle C. Smith made his mark in industry. The mark will long endure because the mettle of the man has been etched deeply in the metal he served so well. Mr. Smith was a man of steel.

Management Conf. to Feature 15 Papers

As the program now stands, 15 papers and one panel discussion will be presented at the Eighth Annual Engineering Management Conference in Chicago Sept. 15-16. The AIME is one of the seven principal sponsors for the Morrison Hotel meeting.

During the opening session on the Theme Impinging Forces, papers will be included concerning *Economic Forces Influencing Engineering Management Decisions* by Ralph Burgess, chief economist, American Cyanamid Co.; and *Impact of Technological Progress on Tomorrow's Management* by E. I. Green, executive vice president, Bell Telephone Laboratories Inc.

Session II will be on New Requirements and New Aids for Managers. J. S. Sayer, general manager, Documentation Inc. will talk on *Mobilization of Data and Information for Technical and Management Decisions.*

Session III, meeting at 9:30 am, Sept. 16th, will have Impact on Professional People as its theme. Impact on Education, the title of Session IV, will feature a talk by H. W. Johnson, vice president–Planning and Research, Inland Steel Co. Mr. Johnson's subject will be *Education and Development of Engineers as Managers at Inland Steel Co.–A Company Experience.*

Registration fee for AIME members and those of other sponsoring societies is $10, which includes the proceedings volume. The fee is $15 to others. Individual papers may be ordered after the Conference through the American Institute of Electrical Engineers, 29 W. 39th St., New York 18, N. Y. They are priced at 50¢ each to members of the sponsoring societies; $1 to nonmembers.

Coming Events

Aug. 28-Sept. 2, Eighth International Symposium on Combustion, California Institute of Technology, Pasadena, Calif.

Aug. 29-31, Metallurgy of Elemental and Compound Semiconductors, Statler Hotel, Boston.

Sept. 1, Chicago Section, NOHC, Golf Outing, Gleneagles Country Club, Chicago.

Sept. 13-16, Eighth Annual Engineering Management Conference, Morrison Hotel, Chicago.

Sept. 19-20, 58th Fall Meeting, Steel Founders' Society of America, The Homestead, Hot Springs, Va.

Sept. 23-24, Southern Ohio Section, NOHC, 24th Annual Technical Conference, Deshler, Hilton Hotel, Columbus.

Oct. 3, Chicago Section, NOHC, Fall Dinner Meeting, Phil Smidt's Restaurant, Hammond, Ind.

Oct. 5-7, Rocky Mt. Minerals Conference, Newhouse Hotel, Salt Lake City.

Oct. 12, Annual Meeting of the Cast Bronze Bearing Institute, Grove Park Inn, Asheville, N. C.

Oct. 12-13, Seventh National Symposium, American Vacuum Society, Cleveland-Sheraton Hotel, Cleveland.

Oct. 12-14, Fourth Conference on Analytical Chemistry in Nuclear Reactor Technology—First Conference on Chemistry in Nuclear Reactor Technology, Gatlinburg, Tenn.

Oct. 13-14, Southwestern Section, NOHC, Fall Meeting, Statler-Hilton Hotel, Dallas.

Oct. 13-15, 1960 Annual Meeting of the Non-Ferrous Founders' Society, Grove Park Inn, Asheville, N. C.

Oct. 17-18, Annual Convention, The Magnesium Association, Pick Carter Hotel, Cleveland.

Oct. 17-20, Fall Meeting of The Metallurgical Society of AIME, Sheraton Hotel, Philadelphia.

Oct. 17-21, Fall Meeting of the Societe Francaise de Metallurgie, Maison de la Chimie, Paris.

Oct. 23-26, Seminar on Rare Earth Research, Arrowhead Center, University of California, Los Angeles.

Oct. 28, Eastern Section, NOHC, 14th Annual Conference, Warwick Hotel, Philadelphia.

Nov. 7, Pittsburgh Section, AIME, 13th Annual Off-the-Record Meeting, Penn-Sheraton Hotel, Pittsburgh.

Nov. 8-11, First National Die Casting Exposition and Congress, Detroit Artillery Armory, Detroit.

Nov. 30-Dec. 2, AIME 18th Electric Furnace Conference, Morrison Hotel, Chicago.

Jan. 18, 1961, Conference on Bar and Allied Products, sponsored by Mechanical Working Committee of The Metallurgical Society, Penn-Sheraton Hotel, Pittsburgh.

Feb. 26-March 2, 1961, AIME Annual Meeting, Chase & Park Plaza Hotels, St. Louis, Mo.

Apr. 10-12, 1961, 44th National Open Hearth Steel Conference and Blast Furnace, Coke Oven and Raw Materials Conference, Sheraton Hotel, Philadelphia.

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Klau-Van Pietersom-Dunlap Inc.

Armour Research Foundation of Illinois Institute of Technology — 604

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Mann-Ellis, Inc.

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Downing Industrial Adv., Inc.

Basic, Incorporated — *
Duffy, McClure & Wilder, Inc.

Bell Telephone Labs. — 595
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McGraw-Edison Co.
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Kudner Agency Inc.

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The Keelor & Stites Co.

Texas Instrument — 597
McCarthy Co. of Texas, The

Union Carbide Metals Co. Div. — 589
Union Carbide Corp.
J. M. Mathes, Inc.

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Columbia-Geneva Steel Div.
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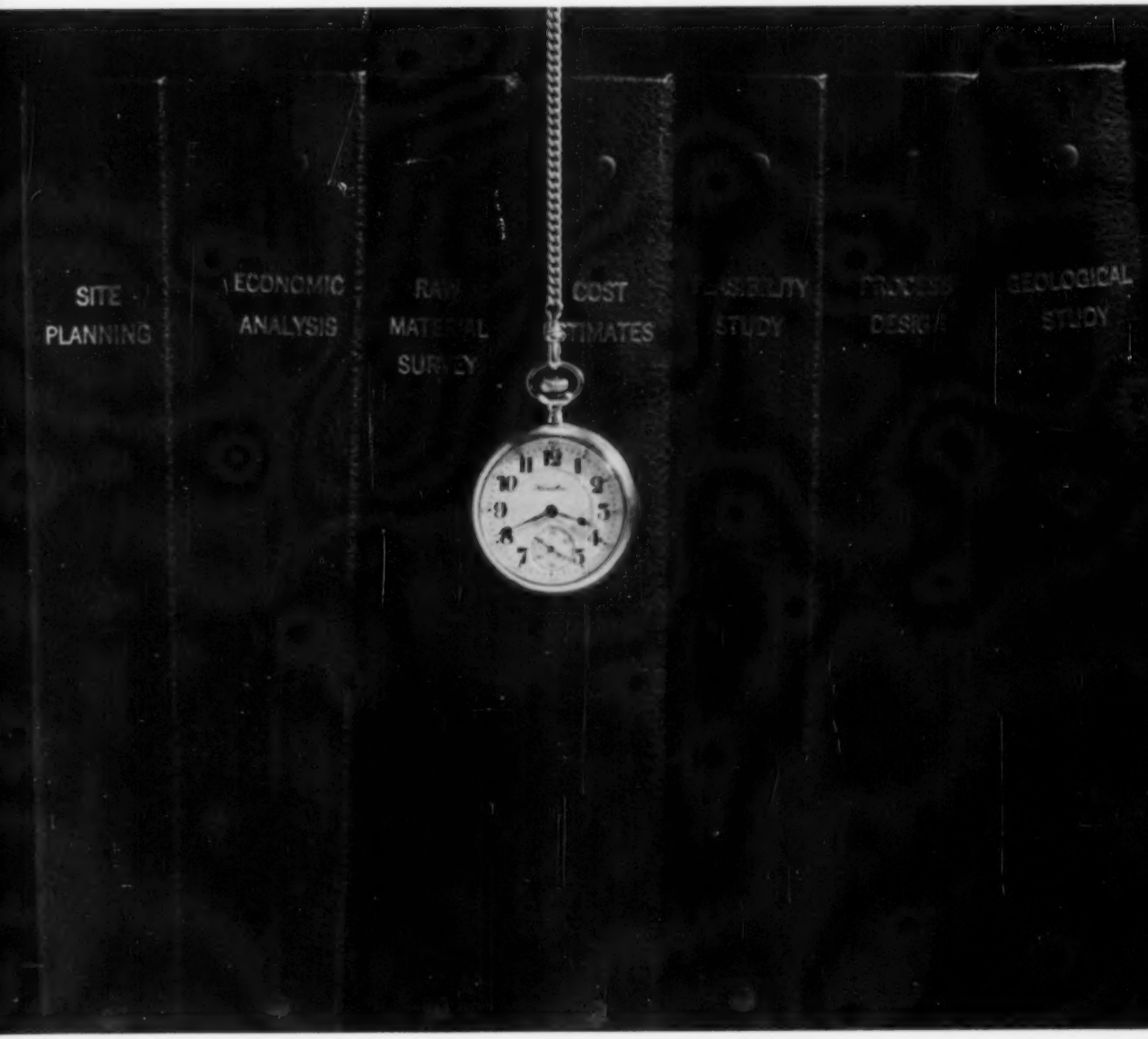

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